Chapter 2
Miter Gates

2-1. Miter Gates, Horizontally Framed

a. Stress analysis. The primary structural elements of a single gate leaf consist of a series of horizontal girders, connected vertically by a skin plate, two end diaphragms, and a number of intermediate diaphragms. (See Plate B-1.) The horizontal girders are in effect a series of three-hinged arches which transmit the water pressures to the lock walls through the quoin hinges. They are subjected to combined bending and direct stresses. The system of vertical diaphragms forms a series of vertical continuous beams supported by the elastic horizontal girders.

(1) In the following general solution for a three-hinged arch, the vertical stiffness of the gate leaf is neglected. Figure 2-1 shows a horizontal girder (half of a three-hinged arch) acted upon by water pressure due to differential head varying in magnitude with the depth of the girder below the water surface and the panel width which it supports. The following symbols are used throughout to describe reactions in the mitered position.

R = reaction of the girder at the wall quoin and miter blocks

N = component of R perpendicular to work line of leaf

P_1 = component of R parallel to work line of leaf

P_2 = the corresponding water force on the end of each girder, determined from the water pressure on the surface extending from the contact point to the upstream side of the skin plate

W = total corresponding water force on each girder, determined by the pressure and the length of the leaf, adjusted by the effective width of damming surface. (See Figure 2-1 and Plate B-3 for the relation of R, N, P_1, and P_2 to the total force W.)

(2) The three-hinged arch formed by the two leaves is symmetrical about the center line of the lock, and, therefore, the miter end reaction R is perpendicular to this center line. If R is extended to intersect the resultant water load W, and from this point of intersection a line is drawn to the point of contact at the quoin end, this line will give the work line which connects the quoin and the miter contact points. The angle θ is the complement of one-half of the miter angle. Referring to Figure 2-1, the bending moment at x distance from the contact point:

$$M_x = \frac{w}{2}\,[L(x) - L(a)\cot\theta + (t-a)^2 - a^2 - x^2] \tag{2-1}$$

Bending moment at center of span x = L/2

$$M_c = \frac{w}{2}\,[L^2/4 - L(a)\cot\theta + (t-a)^2 - a^2] \tag{2-1a}$$

Bending stress in upstream extreme girder fiber:

$$f_{b1} = \frac{w(t-a)}{2\,I}\,[L(x) - L(a)\cot\theta + (t-a)^2 - a^2 - x^2] \tag{2-2}$$

where

I = moment of inertia of the girder

Bending stress in downstream extreme girder fiber:

$$f_{b2} = \frac{w(d-t+a)}{2\,I}\,[L(x) - L(a)\cot\theta + (t-a)^2 - a^2 - x^2] \tag{2-3}$$

Axial stress in the girder:

$$f_a = \frac{w}{A}\,[L/2\cot\theta + t] \tag{2-4}$$

where

A = cross-sectional area of girder

Combined axial and bending stresses:

Upstream flange:

$$f_{c1} = f_a + f_{b1}$$

or

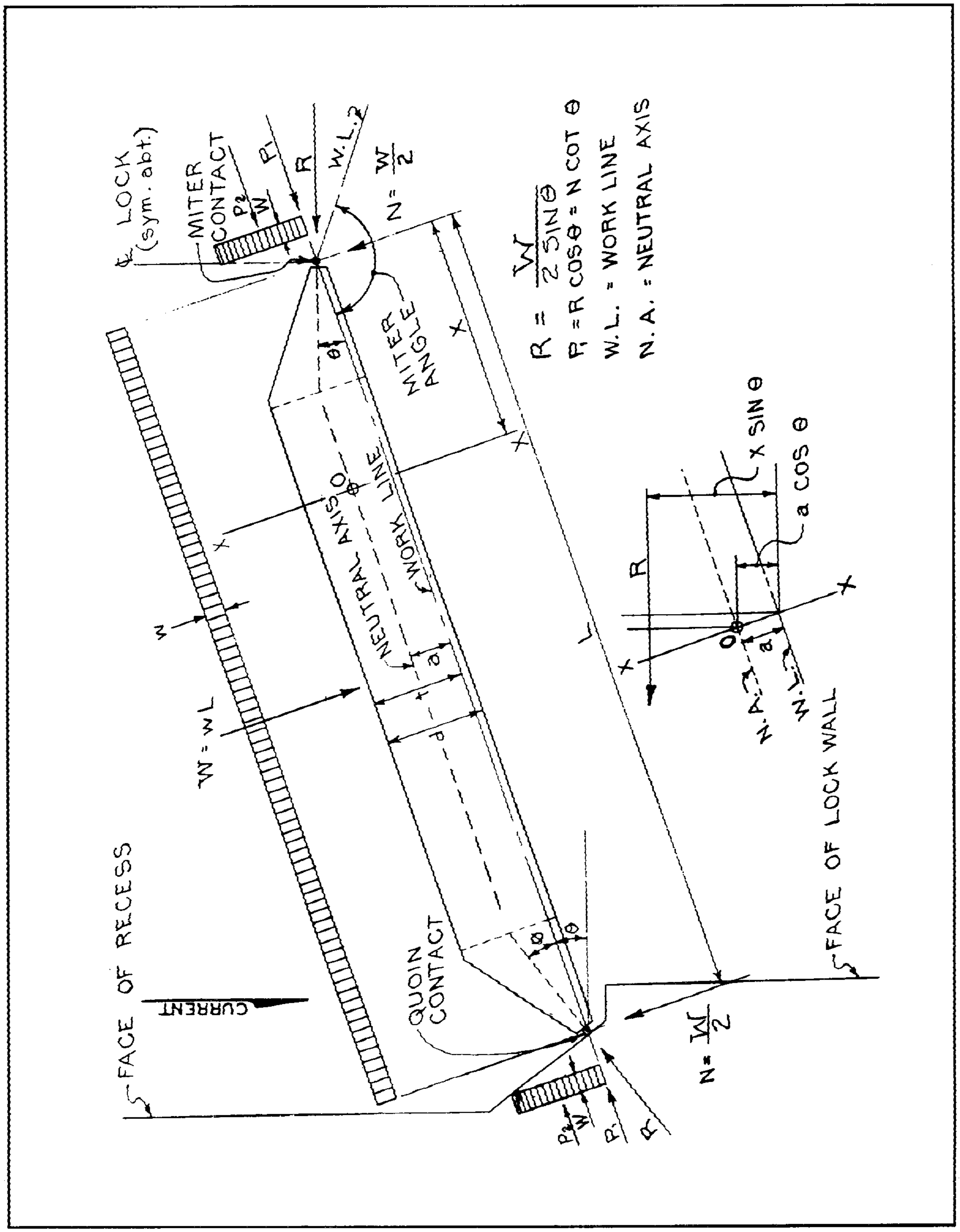


Figure 2-1. Miter gates, horizontally framed, typical girder data

$$f_{c1} = f_a + \frac{w(t-a)}{2\ I}\ [L(x)\ -\ L(a)\ \cot\ \theta + (t\ -\ a)^2\ -\ a^2\ -\ x^2] \tag{2-5}$$

Downstream flange:

$$f_{c2} = f_a - f_{b2}$$

or

$$f_{c2} = f_a + \frac{w(d-t+a)}{2\ I}\ [L(x)\ -\ L(a)\ \cot\ \theta + (t\ -\ a)^2\ -\ a^2\ -\ x^2] \tag{2-6}$$

(3) For small values of x, the downstream flange will be generally in compression. As x is increased toward the midpoint of the leaf, bending stresses will increase so the downstream flange will be generally in tension. Hence, by moving the work line downstream, a saving in weight may be achieved in the center portions of the leaf where the upstream flange is in compression and the downstream flange is in tension or less compression. Considering the girder as a whole, then, the work line should be as far downstream from the neutral axis as is practicable.

(4) The foregoing analysis of the statically determinate forces and stresses affecting the horizontal girders of a gate will serve to indicate approximate dimensions. Common practice is to design the lower girders of the gate for full hydrostatic loads, and to assign loads greater than the hydrostatic to upper girders. These additional loads give greater vertical stiffness to the leaf and approximate tow impact loads.

(5) Initial approximate dimensions may be taken as follows (see Figures 2-1 and 2-2).

(a) A common value for θ is arc tan 1/3 = 18 deg, 26 min, 6 sec, which gives an exact bevel of 1L on 3T (L = longitudinal, T = transverse).

(b) The length of the leaf then becomes 0.527 times the distance between quoin contact points of the gate.

(c) A first trial value, for gates of moderate height, for the depth d may be taken as 0.07 times the length of the leaf, but a minimum depth of 48 in. Refer to paragraph 2-1*d*(3) for additional guidance.

(d) The distance from the downstream girder flange face to the work line (d - t) may be set at a practical minimum of 4 in.

b. Loads and reactions. The following loading conditions represent various combinations of loads and forces to which the gate structure may be subjected:

(1) Loading condition I. Working stresses specified in paragraph 1-7*b* will be applied to loads listed below:

(a) Dead load (including ice, mud, etc., on leaf).

(b) Live load (bridgeway and walkway live loads without impact).

(c) Water pressure (hydrostatic load due to pool differential).

(d) Barge impact load (point of load applied above pool at miter point (symmetric impact), and anywhere to within 35 ft, the standard barge width, of either lock wall (unsymmetric)).

Impact, I = 250 kips (symmetric)
I = 400 kips (unsymmetric)

(e) Gate diagonal prestress loads.

(f) Operating strut loads on gudgeon pin assembly, eye bars, and embedded anchorage. Normal submergence and obstruction are assumed with gate leaf in the recessed and mitered positions.

(2) Loading condition II. When the loading includes in addition to condition I loads any of the loads listed below, a 1/3 overstress of working stresses specified in paragraph 1-7*b* will apply:

(a) Earthquake loads (inertia force of gate mass plus dynamic water load).

(b) Water loads (increased hydrostatic loads due to dewatering for maintenance).

(c) Thermal stresses.

(d) Wave loads, including reverse head due to temporal loads (overfill, overempty, etc.)

(e) Wind loads.

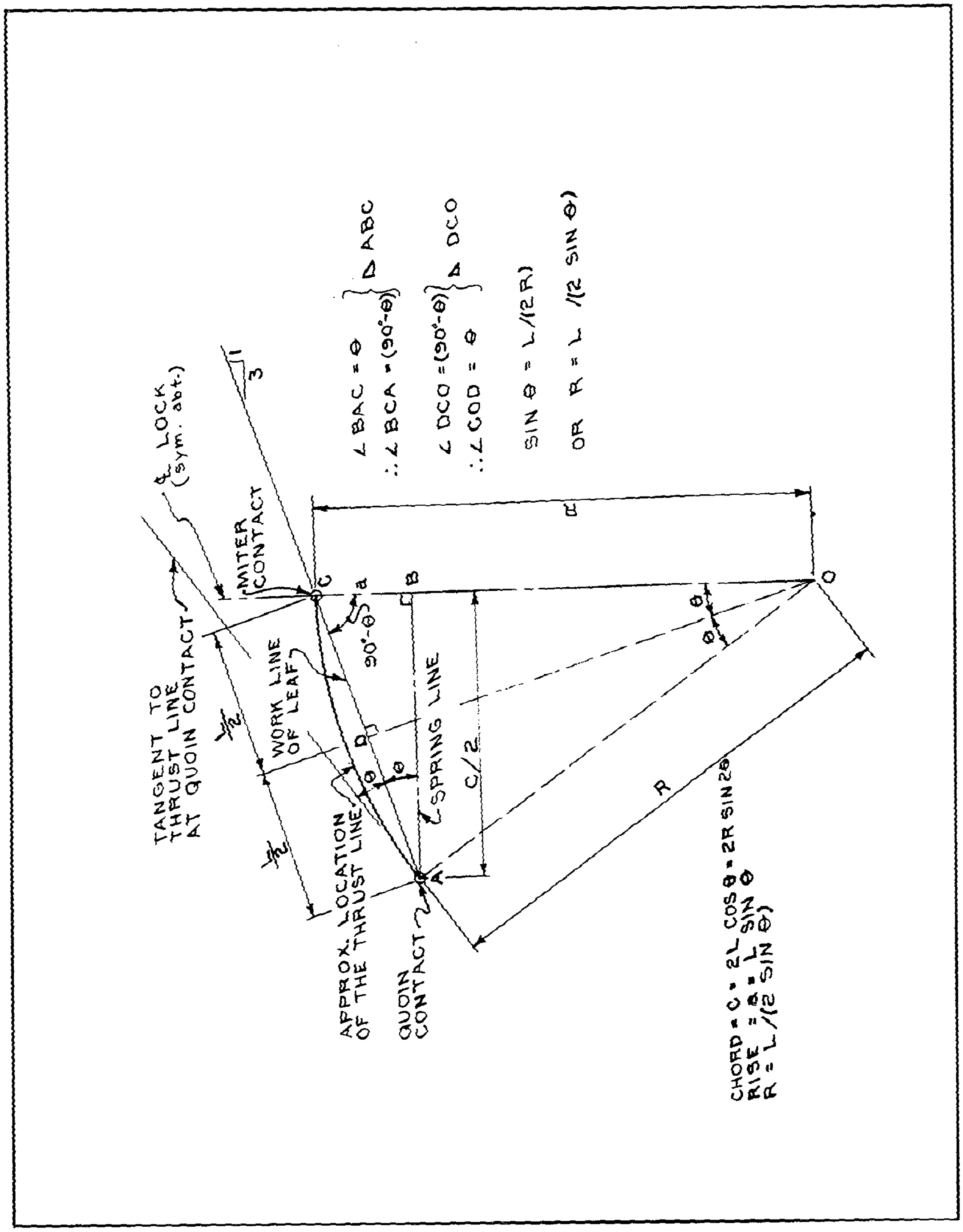


Figure 2-2. Miter gates, horizontally framed, gate geometry

(3) The loads causing gate leaf deflection and torsion during operation of the miter gate are determined as follows: The bottom edge of the leaf is assumed to be held (zero deflection) by water and/or submerged obstruction, the vertical quoin edge is supported by the gudgeon pin and the pintle assembly. Maximum machinery load is applied to the top of the leaf under the above-described edge support conditions. This machinery load deflects the leaf causing an increase or decrease in tension in the prestressed diagonals and torsional stresses in the horizontal girders.

(4) Gate reactions are basically divided into two categories: one, with the gate in the open or intermediate position with no water load; or two, with the leaves mitered and supporting the full hydrostatic load. With the gate in the unmitered (intermediate or open) position, the leaf reactions are couple-forces, applied at the gudgeon pin at the top and the pintle at the bottom. The top couple-force is made up of the gudgeon pin reaction force combined with the operating strut force, while the bottom or pintle force results from the leaf reaction on the pintle. Leaf reaction and strut forces due to all loading conditions defined above will be considered in determining the governing force combinations for design of the gudgeon pin and pintle assemblies. (See Plate B-8.) With the gate adhering and the full hydrostatic load applied, each horizontal girder carries a portion of the water force to the wall monoliths.

c. Skin plate, intercostals, and diaphragms.

(1) Skin plate. The skin plate is located on the upstream face of the girders and is designed for the water load, with the edges of panels assumed fixed at the center line of intercostals and the edge of girder flanges, except that where the flanges are greater than 12 in. wide the skin plate is assumed fixed at a point 6 in. from the center line of the web. The skin plate is also considered an effective part of the upstream girder flange. When a section has a skin plate of a higher yield than the rest of the girder, the effective width of skin plate shall be determined by the higher yield point. Due to the combined loading the skin plate shall be checked for biaxial stress, composed of skin plate action and beam action. The Huber-Mises formula is convenient for checking biaxial stresses.

$$S^2 = S_x^2 - S_x S_y + S_y^2 \tag{2-6}$$

where

S = combined stress $\leq 0.75\ F_y$

S_x = normal stress in x direction

S_y = normal stress in y direction

F_y = minimum yield stress of steel being used

The most effective panel shape for a skin plate is a square, but due to maintaining a uniform intercostal spacing from top to bottom of the leaf, and the variable girder spacing, the panels are usually rectangles, with a ratio of the short side to the long side of the panel, varying from about ± 0.45 at the upper panels to approximately 1.0 on the more critical lower panels. Assuming a rectangular panel with all edges fixed, the following symbols and formulas are used to determine stress in the skin plate from water force only. (See Roark and Young 1975.)

w = unit load at the center line of the panel (average head)

a = greater dimension of the panel

b = smaller dimension of the panel

q = ratio of b to a

t = thickness of plate

Stress at the center line of the long edge =

$$\frac{0.5wb^2}{t^2(1 + 0.623q^6)}$$

Stress at the center line of the short edge =

$$\frac{0.25wb^2}{t^2}$$

(2) Intercostals. Intercostals are designed as vertical fixed end beams supported at the center line of girder webs.

(a) An effective section of skin plate is assumed as acting with the intercostal, the effective width determined in accordance with the AISC Specifications. (Unstiffened elements under compression.)

(b) An average water pressure (head at the center of the panel supported by the intercostal) is used for design of the intercostal, with the loading extending from edge to edge of flanges (maximum of 6 in. from center line of girder web).

(c) When the skin plate is of low-alloy steel and the intercostal is of structural grade steel, the acting composite section of skin plate and intercostal shall be governed by the allowable stress for the lower strength material. (See Figure 2-3 for additional information on intercostals.)

(3) Diaphragms. The end diaphragms are designed as panels acting as skin plate, with the effective panel being between the stiffener angle and the next lower girder. The stiffener is located at midpoint between girders. The head at the center of the effective panel is used as the design pressure. Intermediate diaphragms should be spaced and sized as follows:

(a) To provide adequate supports for horizontal girders (weight and lateral buckling).

(b) For shear forces resulting from the diaphragms tending to equalize differential deflections between adjacent horizontal girders due to variation of hydrostatic and impact loads.

(c) For operating machinery, jacking support, and diagonal tension-related loads.

The critical buckling stress should be kept below 70 percent of the yield stress of the diaphragm material. On smaller gates the intermediate diaphragms are made a minimum of 3/8 in., while the minimum for larger gates is 1/2 in. Generally the end diaphragms are made a minimum of 1/2 in. for all sizes of gates. Diaphragms are made as deep as the girder webs, and stiffeners the same size as the longitudinal web stiffeners are used as vertical stiffeners on the intermediate diaphragms. For determining critical buckling stresses in flat plates in edge compression and shear and establishing allowable diaphragm panel sizes refer to Timoshenko (1936), Bleich (1952), and Priest (1954).

d. Horizontal girders. Horizontal girders lie along a chord of the thrust line curve, with the resulting eccentricity of thrust producing bending stress in addition to the axial stress.

(1) The girders are so spaced that variation in the girder flange sizes and skin plate thicknesses are held to a minimum. The spacing usually varies from a maximum of 6 ft at the top to a minimum of 4 ft at the bottom of the leaf. Each girder should be equal to or smaller than the one immediately below, with the exception of the top girder. Girder spacing also influences the size of intercostals.

(2) The loads on each girder are determined by taking the average water load per linear foot of girder. While this gives slight variation from the exact loading for some girders, (generally two girders per leaf) the average is considered to be more than accurate enough for the usual gate loading. Consideration should be given to any special loading condition to determine if the actual loading should be used instead of the average described above. The boat impact loads are usually governing for the uniformly spaced upper girders.

(3) The ratio of the depth of girder web to the length of leaf varies from 1/8 to 1/15 for most gates, the greater value occurring on gates having the higher heads. Deeper girders make the leaf torsionally stiffer but may require web stiffeners. The appropriate sections of the AISC specifications shall be used to check for web buckling and web crippling. Horizontal girder webs should be stiffened with horizontal stiffeners to meet the criteria for web buckling for axial loaded columns using the diaphragm spacing as the effective column length. Minimum horizontal stiffeners are generally used on girder webs even though not required by web buckling. The minimum width of stiffeners shall be 3-7/8 in., used where the minimum flange width of 8 in. is used.

(4) Minimum thickness of material shall be 3/8 in. for webs and stiffeners and 1/2 in. for flanges. The minimum width of flange plates shall be 8 in. for the upstream flange and 12 in. for the downstream flange, with the exception of the bottom girder. The downstream flange of the bottom girder can be a minimum of 9 in. wide, with 3 in. below the center line of the web to provide additional clearance between bottom girder and sill. For the end sections of the bottom girder, where the downstream flange is heavier, the upper portion of the flange can be made a maximum width of 15t above the center line of the web, maintaining the 3 in. below the web center line and limiting the overall width of the flange to 1 ft 3 in. For all other flanges the maximum overall width should be limited to 24t, thereby reducing the possibility of flanges being undesirably wide and thin. The use of cover plates is not recommended for the usual gate design. (See Plates B-3 and B-5.)

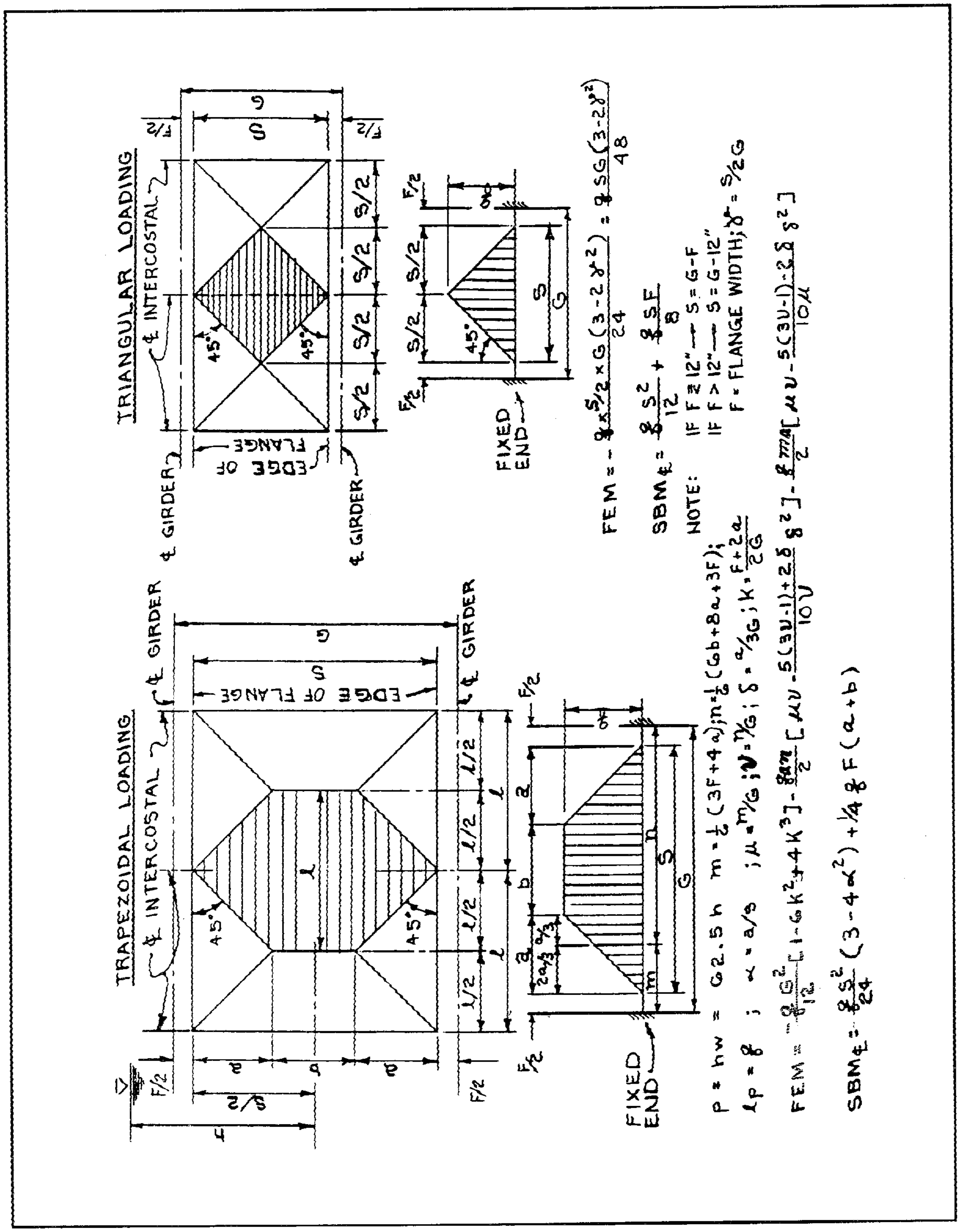
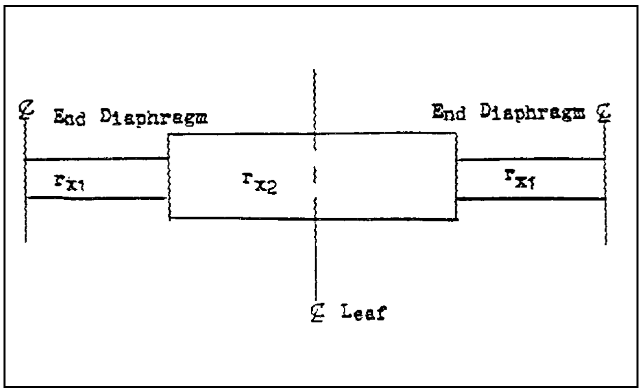


Figure 2-3. Miter gates, horizontally framed, intercostal loadings

(5) The maximum extension of skin plate above the center line of the top girder is 8 in., to prevent interference with the operating strut. The maximum extension of skin plate above the top flange should not be over 1/2 in., limiting the maximum width of the upstream flange for the top girder to 1 ft 3 in.

(6) Buckling of the girder about the major axis is not a concern since the skin plate provides lateral support to each girder. However, lateral stability of the downstream flange should be checked where that flange is in compression near the end diaphragms.

(7) The girder should be checked for buckling about the minor axis. The length shall be taken as the distance between quoin and miter bearings, with K = 1. The radius of gyration to be used may be calculated for the center part of the girder. However, this may be slightly overconservative. If this calculation shows that buckling strength is a controlling condition, use the following more realistic value for the radius of gyration.



$$r_x = (L_1 \ x \ r_{x2}) + \frac{2(L_2 \ x \ r_{x1})}{L_1 + 2(L_2)} \qquad (2\text{-}7)$$

where

r_{x1} and r_{x2} = major axis radius of gyration of respective sections

L_1 and L_2 = lengths of respective sections

For additional information, see USAEWES (1987).

(8) The web depth-to-thickness ratio should be such that no reduction in flange stress is necessary. See the AISC specifications for the maximum ratio.

(9) Transition of flange widths at butt joints shall be governed by the applicable provisions of Structural Welding Code, AWSD1.1. The maximum change in flange width, on the same edge of a girder web, shall be 6 in., with a 3-in. differential on each edge of the flange, with the exception of the downstream flange of the bottom girder, where the total 6-in. differential may be on the upper edge of the flange. This applies between the section at the center line of a girder, where the upstream flange is a maximum width and the downstream flange is a minimum width, and a section at the end of a girder where the upstream flange is a minimum width and the downstream flange is a maximum width. A tapered flange transition is also preferred where all horizontal and vertical flanges connect to gusset plates with the maximum change being as previously described.

(10) The flanges of the bottom girder are offset from the center line of the girder web as indicated by the preceding paragraphs. The downstream flange should extend 3 in. below the center line of the girder web, from end to end of girder, to allow for clearance between the flange and the sill. The upstream flange should extend 6 in. below the center line of the girder web, from end to end of girder, with the skin plate 1/2 in. above the lower edge of the flange. A minimum of 4 in. should be used above the center line of the web, thereby making a minimum width of 10 in. for the upstream flange of the lower girder. (See Plate B-5.)

(11) The load in the diagonal is resisted by members connected to the gusset plate. The horizontal component of this load is distributed among several girders. The design of all girders attached to the gusset plate shall include provisions for this additional eccentric axial load. A discussion of the distribution of this load among the girders may be found in Technical Report ITL-87-4, Report 7 (USAEWES 1987).

(12) Drain holes shall be provided in all girder webs except the top girder where the drain holes shall be placed in the upstream flange, since the web of the top girder forms part of the damming surface during high water.

(13) The critical point for the tapered end sections occurs at a distance Z' from the center line of bearing.

$$Z' = \frac{\text{span} - 16t}{2}$$

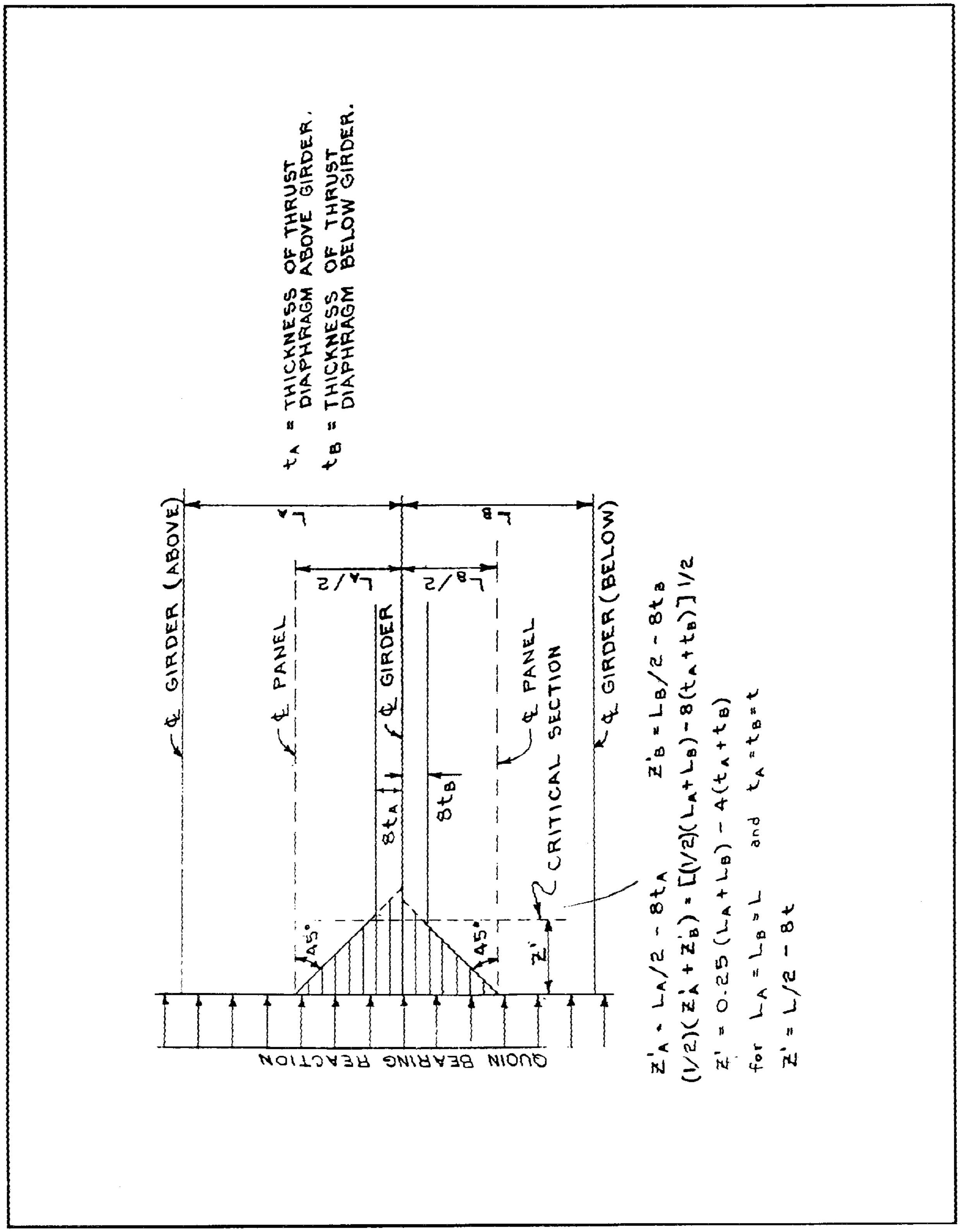


Figure 2-4. Miter gates, horizontally framed, load distribution, tapered end

where the span is the smaller span adjacent to the web under consideration and *t* is the thickness of the thrust diaphragm. (See Figure 2-4.) Due to the short lengths involved, F_a and F_b are equal to the basic stress of 0.50 F_y.

(14) The moment is determined by assuming a cantilever section equal in length to Z' with a water load equal to w, plus the moment created by R being eccentric from the centroid of the section. See paragraph 2-1*e* on the thrust diaphragm for more information relating to the distribution of stress from the end plates to the webs.

(15) The web thickness of the tapered section is increased to keep the stress within the allowable limits. If a thicker tapered end web is required, this thickness is carried 12 in. past the end diaphragm. This may vary on the bottom girder where the stiffeners for the jacking support may interfere. A check should be made for concentrated stresses in the web just inside the end diaphragm. This stress is caused by the thrust diaphragm ending, transferring its load into the web. It is recommended that 20 percent of the thrust diaphragm load and an area of 40 percent of the web depth and corresponding thickness, including any stiffeners in the area, be considered for the check. The bottom girder web thickness over the pintle is 3/4 in. minimum and machined to a 250 finish or match the machine finish to the top of the pintle socket casting. (See Figure 2-5.) The top and bottom webs are wider at the quoin end to accommodate the gudgeon pin and pintle. (See Plates B-3, B-4, and B-5 for additional information on girders.)

e. Thrust diaphragms. The thrust diaphragm is tangent to the thrust curve at the contact point and is approximately in line with the thrust curve between the contact point and the end diaphragm, which is the limit of the thrust diaphragm. The thrust diaphragm serves to distribute the reaction of the girders from the quoin block into the girder webs. It also acts as the damming surface between the end plate and the end diaphragm. Part of the thrust diaphragm is also considered effective in the quoin post, making it subject to bearing, skin plate, and column action stresses. Shear between the web and thrust diaphragm is to be checked also, but is not combined with the above-listed forces. The allowable stress for the combined bearing and skin plate action, occurring adjacent to the end plate, is limited by the elastic limit or 0.70 F_y, whichever is the lesser value. The stress in the thrust diaphragm is assumed to follow a 45-deg angle from a point midway between girders, up to the effective web section. The effective section consists of the web, flanges, and a portion of the thrust diaphragm. See Figure 2-4 for the layout of this stress pattern for the tapered end section. The elastic limit may be determined by assuming the panel under consideration to be clamped on all edges and equal uniform compression on two opposite edges, with the critical stress equal to $K[E/(1 - v^2)](t/b)^2$

where

a = longer dimension of panel

b = shorter dimension of panel

v = Poisson's ratio

t = thickness

K = 7.7 for a ratio of a/b = 1.0

K = 6.7 for a ratio of a/b = 2.0

K = 6.4 for a ratio of a/b = 3.0

See Roark and Young (1975) for additional information on elastic stability.

f. Quoin post. A section of the thrust diaphragms, vertically from top to bottom girders, forms a column to support the dead weight of the leaf. The end plate and two vertical stiffeners form one flange of the column; a plate perpendicular to the thrust diaphragm, with vertical stiffeners on the outside edges, form the other flange. See Plate B-5 for a typical layout of the quoin post. The axial load on the quoin post consists of the dead weight of the leaf plus ice and mud load. Due to the eccentricity of the pintle and gudgeon pin with respect to the centroid of the quoin post, the quoin post is subjected to an axial stress and bending stresses, plus the skin plate action of the thrust plate.

$$\text{Stress} = \frac{P}{I} + \frac{Pec}{I_x} + \frac{Pec}{I_y} + \text{skin plate stress} \qquad (2\text{-}8)$$

The maximum combined stress may occur at the center of the lower edge of the thrust diaphragm panel, shown as point C or at any of the extreme corners of the quoin post cross section shown as points A, B, E, and F in Plate B-5. The allowable stress for the combined loading is limited to the basic stress of 0.50 F_y.

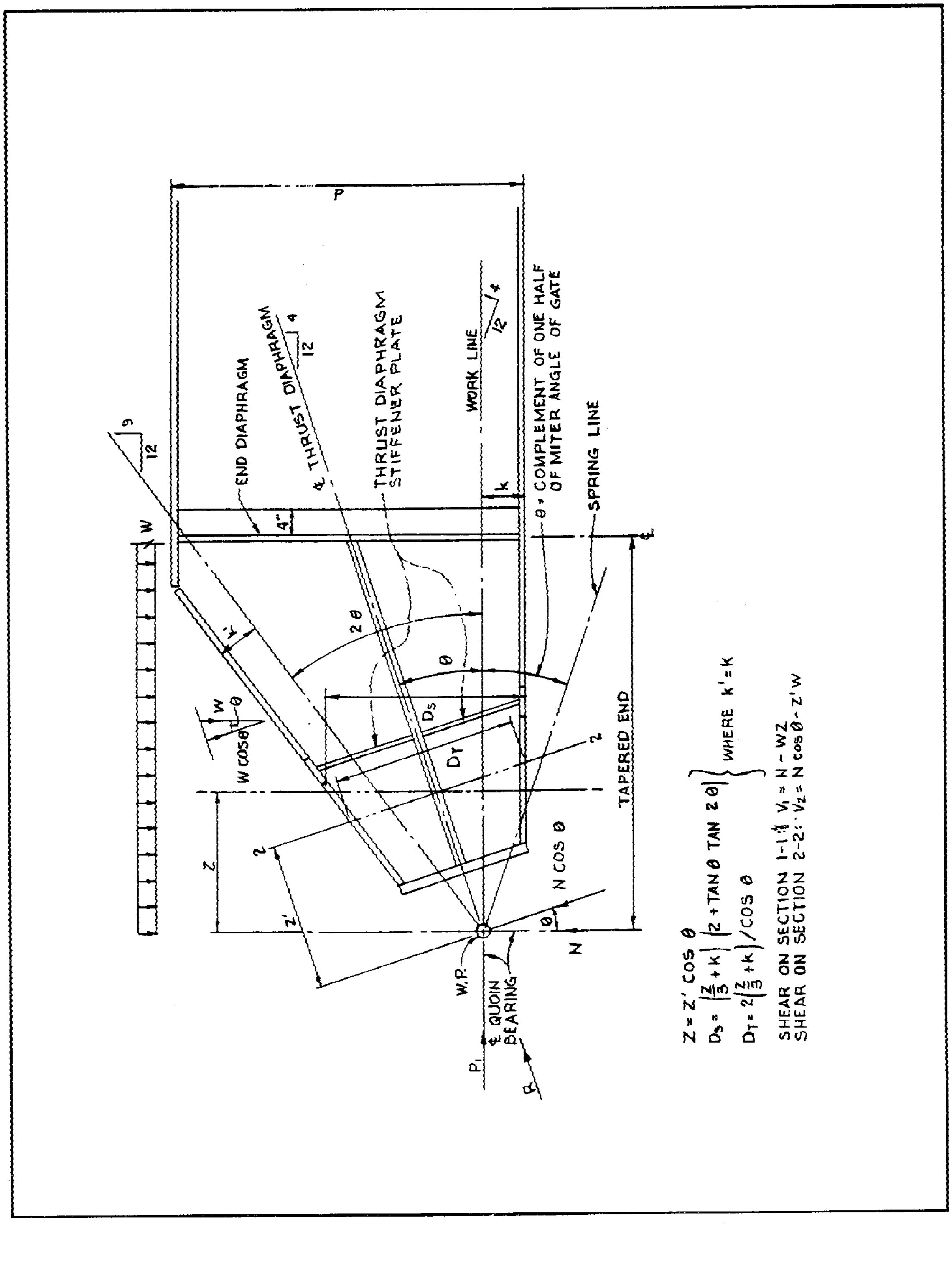


Figure 2-5. Miter gates, horizontally framed, typical end shear, tapered end

g. Gudgeon pin hood and anchorage.

(1) Gudgeon pin and hood. The gudgeon pin hood is an arrangement of plates forming the hinge connection at the top of the miter gate leaf. (See Plate B-6.) The commended distance between the center line of the top web and the center line of the top pin plate is 1 ft 6-3/4 in. This is with a 1-in. top pin plate and 1-1/4 in. pin plate welded to the top girder web. The top pin plate has sections of it sloping from the 1 ft 6-3/4 in. height down to the girder web. The downstream edge of the top pin plate is attached to the 1/2-in. section of the bulkhead plate with a weld. The upstream part of the hood is formed by a vertical plate, normally 3/4-in. minimum thickness, that overlaps the upstream girder flange, with the edge of the vertical hood plate being welded on the center line of the horizontal girder web.

(a) The top pin plate should be designed as a curved beam with a uniform load rather than assume the plate to be an eye bar. Formulas from Seely and Smith (1952), are shown in Plate B-7. The basic stress of 0.50 F_y should control.

(b) The pin is generally made a minimum of 12 in. in diameter, to give an additional factor of safety and to standardize the barrel and hood arrangement.

(c) The pin is usually made of forged alloy steel, ASTM A668, normalized and tempered, with the allowable stresses as referenced in paragraph 1-7*b*.

(d) The bushing is normally of bronze with the bearing pressure kept below 1,500 psi.

(e) Rings of ASTM A36 steel varying in thickness from 1/16 in. to 1/4 in. are used to adjust the vertical clearance between the gudgeon pin barrel and the pin hood.

(2) Anchorage. The anchorage system supporting the miter gate leaves is divided into four basic categories: (a) gudgeon pin barrel, (b) anchorage links, (c) embedded anchorage, (d) pintle and pintle base. While these components act together as a unit, each is designed as an individual unit. The force applied to each of these units is the resultant force of the combined strut force and the dead weight of the leaf, increased 10 percent for impact. The governing loads usually occur at the recessed (open) or mitered (closed) positions of the gate leaf. In order to develop maximum operating strut forces the leaf is assumed obstructed near its miter end. The anchorage system is also checked for temporal loads. (See Plates B-11 and B-15 for the layout of typical anchorage systems.)

(a) Gudgeon pin barrel. The gudgeon pin barrel, of welded carbon steel plates or forged alloy steel plates, is designed as a continuous beam supported by vertical stiffeners, and at the same time as a curved beam, made up of a horizontal plate and an effective section of the plate cylinder which forms the pin barrel. The minimum thickness of the barrel or horizontal plate should not be less than 1-1/2 in. See Plate B-9 for a typical barrel arrangement and formulas. The alternate method of analysis shown in Plate B-10 may be used in lieu of the more precise method beginning in Plate B-9. While the alternate method stresses vary from the more accurate method, the variations are on the conservative side. Due to the barrel being a critical item the design stresses should be kept low, in the range of approximately 0.33 F_y, using the yield point of the lowest grade steel used in the composite barrel unit. This stress should be the combined stress due to bending and direct stress.

(b) Anchorage links. The links are made up of pinned ends connecting to the embedded anchorage with a threaded section between the embedded anchorage and the gudgeon pin. Each link is designed as a tension or compression member individually, and the two links are checked as a unit, as shown in Plate B-11. An alternate top anchorage is shown in Plate B-15. This assembly is made up of two anchor arms and two gudgeon links. The links are welded to the arm which is normal to the face of the lock wall. Adjustment of this anchorage assembly is accomplished by means of wedges. The design procedure is as described above. The design tension force is the tension load plus 10 percent impact, and the design compression force is the compression load plus 10 percent impact. The links acting as a unit are assumed to have a maximum misalignment of 2-1/2 in. at point B, shown in Plate B-11. This introduces a bending stress in conjunction with the axial load. Allowable tension and compression stresses should be determined in accordance with fatigue criteria of ASSHTO Standard Specifications for Highway Bridges or in accordance with paragraph 1-7*b* of this manual, whichever governs. The threaded section of each link, made up of a forged steel section a minimum of 6 in. in diameter, and a hexagonal sleeve nut are used for adjustment of the gate leaf. Right- and left-hand threads, giving a turnbuckle effect, are recommended, with 1/2-in. square threads being used for the sleeve nuts. After all adjustments to the gate leaf have been made, a channel may be welded between the sleeve nuts to lock them in place. The outside diameter of the section threaded for the sleeve nut should be the same as the largest dimension of the rectangular section. The rectangular section of the link, a minimum of 6 in. by 4 in., is also made of forged steel. The pin-connected ends of the rectangular sections are designed as eye bars, with the allowable stresses being 83 percent of those shown in AISC. Pins should be designed for both bending and bearing, with the allowable stresses determined as indicated in paragraph 1-7*b*. The dimensions and sizes shown in Plate B-11 are recommended as a minimum unless special conditions or loadings warrant a variation in some dimensions.

(c) Embedded anchorage. In order to distribute the top reaction of the leaf into a larger segment of concrete, the embedded anchorage is designed as a triangular unit, composed of a heavy member for the hypotenuse and vertical side and a secondary member for the horizontal side. The vertical and horizontal sides of the triangle are normally 9 ft with the hypotenuse forming a 45-deg triangle. The hypotenuse and vertical member are designed as a column or tension member, depending on the direction of the gate reaction. The horizontal or secondary member is for fabrication and construction and is assumed to carry no design load. The reactions of the triangular unit are applied to the concrete through plates or pads on the lower points of the triangle. Bolts are used in conjunction with the bearing plates, with the bolts prestressed so that bearing on the concrete will never be completely relieved by the loads from the gate leaf. See Plates B-12 and B-15 for typical layout of embedded anchorage. The prestressed bolts should have an anchor at the ends to carry the full load, assuming no load transfer through bond and using mastic to prevent bond on the bolts. Bolts should be sized according to load, and the length should be sufficient to extend into at least two lifts of concrete. The use of strain gages or an ultrasonic bolt stress monitor is recommended for determining the desirable loads in the prestressed bolts, as the nuts sometimes bind on one edge and thereby distort torque readings and make the turn of the nut method difficult.

h. Pintle assembly. The pintle and related components support the dead weight of each leaf of the miter gate. The unit is made up of four major components: (1) pintle socket, (2) pintle, (3) pintle shoe, and (4) pintle base. (See Plates B-13 and B-14.)

(1) The pintle socket is made of cast steel and is connected to the bottom of the lower girder web with turned monel or stainless steel bolts. The bolts are sized to carry the gate leaf reaction in shear, but, as an added safety factor, a thrust plate should be welded to the underside of the bottom girder web, with a milled contact surface between the plate and pintle socket. The minimum plate size should be 1-1/4 in. in thickness and 12 in. wide, with a length as required by the girder web. The socket encloses the bronze bushing which fits over the pintle ball. An allowable bearing stress of 1,500 psi is desirable but may not always be practical. The automatic greasing system allows a higher bearing stress but should not exceed 2,500 psi. See Plate B-13 for additional information.

(2) The pintle, generally made of cast alloy steel with a nickel content of 3 to 5 percent, is usually 10 in. to 20 in. in diameter, with the top bearing surface in the shape of a half sphere and a cylindrical shaped bottom shaft. For salt or brackish water locations, pintles should be of forged alloy steel with bearing surfaces of corrosion-resisting steel deposited in weld passes to a thickness of not less than 1/8 in. and machined to the required shape. The pintle ball and bushing are finished to a 16-microinch finish where the two come in contact.

(3) Pintle assemblies used for horizontally framed miter gates are generally two types: fixed and floating.

(a) Fixed pintle. This type of pintle is recommended for new construction and major gate rehabilitation. The pintle fits into the pintle shoe, which is bolted to the embedded pintle base. The degree of fixity of the pintle depends on the shear capacity of the pintle shoe bolts. The pintle should be designed so that after relieving the load on the pintle by jacking, the pintle assembly is easily removable. See Plate B-16 for typical fixed pintle. The pintle base, made of cast steel, is embedded in concrete, with the shoe fitting into a curved section of the upper segment of the base. The curved section, of the same radius as the pintle shoe, is formed so that under normal operation the reaction between the shoe and base is always perpendicular to a line tangent to the curve of both shoe and base at the point of reaction.

(b) Floating pintle. This type of pintle is not recommended for new construction. The pintle is fitted into a cast steel shoe, with a shear key provided to prevent the pintle from turning in the shoe. The shoe is not fastened to the base, thereby allowing the gate leaf to move outward in case of debris between the quoin and wall quoin preventing the leaf from seating properly. See Plate B-13 for typical floating pintle. Damage to the pintle bearing has occurred frequently with this type of pintle due to the relative movement between the pintle shoe and base. The movement can consist of the shoe sliding on the base during leaf operation from either the mitered or recessed position, until the leaf reaches approximately the midposition, at which time the shoe slides back against the flange on the base. This type of movement is generally visually detectable and causes serious wear. However, an alternative to the floating circular shoe is to make the shoe three sided with one corner having the same radius as the circular shoe, and attach a steel keeper bar to the embedded base in front of the shoe. This would prevent the shoe from rotating on the embedded base and prevent the pintle from moving out of pocket. Again, the degree of fixity would depend on the shear capacity of the bolts in the keeper bar. This alternative will meet the requirements of the fixed pintle as well as the capacity to minimize damage in case of emergency.

(4) The pintle base is designed so that there will be a compressive force under all parts of the base. The value of the compressive force on the concrete will vary from a maximum on one edge to a minimum on the opposite edge. Computations are based on that portion of the pintle above the point under consideration acting as a composite unit. The overturning moment can be found from the horizontal force on the pintle and will be resisted by the reaction on the section being investigated. The eccentricity of the vertical force can be determined by the angle the resultant makes with the horizontal and the distance between the horizontal force on the pintle and reaction on the pintle base.

(5) The center line of the pintle (vertical axis of rotation) is located eccentric (upstream) relative to the center of curvature of the bearing face of the quoin contact block. This center of curvature is on the thrust line. The center line of pintle should be located on the point of intersection of the bisector of the angle formed by the mitered and recessed gate leaf work lines and the perpendicular line from the bisector to the quoin contact point resulting in an offset of approximately 7 in. as in the details shown in Plate B-4. Studies and experience show that eccentricities arrived at by the above-described method will reduce the contact time between the fixed wall quoin and the contact block of the moving gate leaf sufficiently to minimize interference and binding between the bearing blocks. The 7-in. offset will be exact and constant for all gates with the same miter angle and distance from the face of lock chamber to the recessed work line (1 ft 2-1/2 in.) as shown in Plate B-4 and in the example in Appendix C.

i. Operating strut connection. The operating strut connection for horizontally framed gates is generally one of three types, the basic types being the hood, vertical shaft, and direct acting cylinder. Each type has its advantages and disadvantages, and the selection of which o use can only be made after considering all pertinent factors. The different types are described below with some of the main characteristics given for each one.

(1) Hood-type connection. This connection, commonly used with the Panama, Modified Ohio, or the Ohio type machine is attached to the top girder on a line through the center of the pintle and parallel to the work line of the leaf. Three vertical diaphragms, usually one of the regular intermediate diaphragms and two additional diaphragms, spanning between girders one and two, support the connection in the vertical direction. The hood is designed for both moment and shear with a standard rolled tee, under the center of the pin, and spanning between the vertical diaphragms. The stem of the tee is welded to the underside of the top girder web and the ends of the tee are welded to the three vertical diaphragms. The strut is connected to the hood by two pins, one larger vertical pin and a smaller horizontal pin through the vertical pin, forming a universal joint to minimize moment in the strut. The vertical pin is designed for both moment and shear, with the pin supported by bearing collars and bushings at the upper and lower ends. The bearing collars are attached to the supporting horizontal plates by turned bolts, which are sized for shear. Shear normally will determine the size of the horizontal pin. Plate B-33 shows typical details for the hood-type connection.

(2) Vertical-shaft-type connection. This connection consists of a vertical cylindrical shaft extending through the web of the top girder down to the web of the second girder. It has generally been used with a cylindrical or tubular strut utilizing ring springs. As the shaft is free to rotate in its supporting bearings it is designed for simple moment and shear, with the restraining forces supplied to the shaft by the webs of the first and second girder webs. This arrangement is similar to the vertical pin in the hood type with the exception that the shaft is tapered between the first and second girders. The pin is designed as a cantilever above the top girder. The vertical-shaft-type connection is similar to the vertical pin of the hood-type connection; therefore the details of the vertical shaft connection are not shown in the plates in Appendix B.

(3) Direct-acting-type connection. This connection, while not restricted to them, has normally been used only for direct-acting-cylinder machines. It is bolted directly to a section of the upstream flange of the top girder which is increased in width and thickness and supported by transverse stiffeners on each side of the girder web.

The flange section is designed as a simple beam supported by the stiffeners. The length of the increased section is determined by fabrication requirements and shear between the section and the web. The operating strut, connected by the same universal-type joint as the hood type, consisting of vertical and horizontal pins, applies no moment about the weak axis of the pin plates and eliminates any force except direct forces being applied to the girder flange. See Plate B-33 for typical arrangement of this type of connection.

(4) Comparison of types. The hood-type connection, located on a line through the center of the pintle, avoids increased anchorage forces created by a moment arm from the upstream flange to the center of the pintle. This keeps R_b, as shown in Plate B-8, to a minimum force. The fabrication cost for the hood type will generally be higher than for the other types of connections.

(a) The vertical shaft system is a simpler type of connection than the hood type, and it is also located on a line through the center of the pintle, thereby keeping force R_b to a minimum. The cantilevered length of the shaft above the top girder may be prohibitive for the helical coil spring and wide-flange-type strut.

(b) The direct-acting-type connection is the simplest of the three connections, but as the pin plate assembly is bolted to the upstream flange of the type girder it will, in general, require a wider wall recess if used with machinery other than the direct-acting cylinder, due to having to move the machine back from the face of the lock wall. If the machine is kept in the same position as for the hood- or vertical-shaft-type connections, the strut would have to be reduced in length, thereby creating potential interference between parts of the strut.

(c) As was previously stated, each type of connection has its advantages and disadvantages and final selection of the type to use can only be made after carefully evaluating all aspects of each individual gate, weighing cost against efficiency, maintenance, and effect on other segments of the gate or anchorage.

j. Diagonals. Each leaf of a miter gate is similar to a cantilever beam. The skin plate has such a great vertical stiffness that the diagonals are necessary only to counteract the torsional or twisting action on the leaf. (See Plate B-17.)

(1) The basic formulas and information for the design of diagonals are covered in "Torsional Deflection of Miter-Type Lock Gates and Design of the Diagonals" (USAED Chicago 1960). (See Chapter 3 of this manual for additional information.)

(2) The stiffness of welded miter gates appears to be considerably greater in most cases than the manual indicates. While this does not affect the overall pattern of diagonal design, it should be kept in mind when selecting the values for deflection of the leaf.

(3) The diagonals may be pin connected or welded to the gusset plates. Turnbuckles or brackets on the end of the diagonals are recommended for prestressing the diagonals. Brackets are generally located on the lower end of the diagonals. However, the brackets on the newer locks in the Ohio River Division are located on the upper end of the diagonals for better surveillance. An advantage of the brackets is that no compression can be placed in the diagonal during prestressing. It is noted that the fatigue strength of the welded connection may govern the design when welding instead of pinning the diagonals to the gusset plates. Studies have shown that the most important factors which govern the fatigue strength of cyclically loaded members are the stress range and the type of details used. The AASHTO Standard Specifications for Highway Bridges, Section 10.3, allows only a stress range of 13,000 psi and 8,000 psi for 500,000 and 2,000,000 cycles, respectively, for fillet weld Category E.

(4) Strain gages installed with instant-setting cement or strain transducers should be used for determining the stress in each diagonal.

(5) The maximum stress, for temporary conditions, should not exceed 0.75 F_y. See Plate 17 for typical information on diagonals.

k. Miter and wall quoins.

(1) Miter blocks. Miter blocks are usually 8-in. by 5-1/2 in. rectangular blocks with one miter block having a concave surface with a radius of 1 ft 6 in. and the other having a convex surface with a radius of 1 ft 4-1/2 in. located at the miter ends of the leaves. These blocks are made up of 15- to 20-ft-long sections with transverse joints occurring at the center lines of horizontal girder webs. Together with the thrust diaphragms and end plates the miter blocks distribute the axial load from the horizontal girders in the vertical direction and form a contact bearing surface between the miter ends of the leaves. Jacking and holding bolts are used for temporary supports and adjustment of the miter blocks to assure full contact between leaves in the mitered position.

(2) Wall quoin. The quoin block on the lock wall is essentially the same as the miter block with the wall quoin having the concave surface with a 1-ft-6-in. radius and the quoin block on each leaf having a convex surface with a 1-ft-4-1/2-in. radius. There are two recommended types of wall quoin systems. The first system, an adjustable type, consists of a 10-in. by 3-1/2-in. bar, welded to a 1-1/4-in. by 1-ft-5-in. base plate. The base plate is attached to a vertical beam with jacking and holding bolts to facilitate adjustment and replacement. The vertical beam is embedded in second-pour concrete and transmits the quoin reaction forces into the wall. The space between the base plate and the embedded beam is filled with an epoxy filler after final adjustments have been made. The second system, a fixed type, consists of a 10-in. by 3-1/2-in. bar, welded to a vertical beam which was described previously. This type is more desirable when using zinc as a backing material because the high temperatures involved may damage the concrete.

(3) Material for quoins. Adjustable and replaceable corrosion-resisting clad steel or solid corrosion-resisting steel blocks are recommended for both miter and wall quoins. The minimum size bolts used for installation and adjustment should be 3/4 in. in diameter. Plate B-18 shows typical quoin and miter block details.

(4) Backing material. After final adjustments have been made to the miter and quoin blocks, a gap of about 1/2 in. between the end or backing plate and the blocks is filled with zinc or an approved epoxy filler. The filler layer assures a uniform transfer of the loads from the leaf into the blocks. Although epoxy is now more widely used, the contractor may be given the option of using either zinc or epoxy or the district may wish to dictate which is to be used based on their past success. In the past, epoxy was easier and safer to work with but new types of equipment for heating zinc and preheating the ends of the gate leaves have greatly reduced many objections to its use. The initial investment in the equipment needed in using zinc is expensive and the placement may be slightly more expensive, but with the life expectancy of zinc being 2 to 4 times that of epoxy, the use of zinc will be less expensive during the life of a project. Precautions should be taken to prevent leakage of either filler, and to prevent air entrapment. Application of a bond-breaking material to jacking bolts, holding bolts, and contact surfaces should be made, and the manufacturer's installation instructions should be followed explicitly. Where zinc is used, a seal weld is needed at the end joints of the blocks after cooling. Welds should be ground smooth to prevent interference with bearing surfaces. Where epoxy is used, fresh, properly stored epoxy filler material mixed under clean and dry conditions should assure its functional performance.

(5) Cathodic protection for quoins. When carbon steel quoin and miter blocks are installed, they are bolted to the gate with zinc or Nordback in back of them. The blocks and the zinc can be protected with cathodic protection. As a minimum, the sides of the blocks can and should be painted. The miter and quoin faces are protected with protective potentials in the same manner as the gates.

l. Seals. Rubber seals should be installed on the bottom of each leaf to seal the gate to the miter sill. Various types of seals have been used by the different districts and divisions with varying degrees of success. The seal should give a reasonable degree of watertightness but some leakage is to be expected. Excessive leakage is objectionable when the lower portion of the gate is exposed.

(1) Where a large temperature range is encountered the 4-in. round rubber seal appears to be satisfactory. This type of seal allows for the effective shortening or lengthening of the leaf, which causes the leaf to change positions with respect to the sill. This seal allows the upper pool to force it against the gate leaf, eliminating possible vibration. The curved section around the pintle generally utilizes the J-type seal, the shape and size of the 4-in. diameter rubber seal not being conducive to sharp bends. The sill concrete is second pour around the embedded portion of the seal. See Plate B-21 for details.

(2) Where the temperature range is such that the variations in leaf length are small, the so called "Pork-chop" type seal has been used. The sill angle for this type of seal is in second-pour concrete, with all adjustments made before placing the second pour. This type of seal also reduces the probability of vibration encountered with the J-type seal. See Plate B-21 for details.

(3) Although the seal arrangements described above have provided satisfactory service in the past, they are subject to vibration and damage from debris and are not recommended for new construction.

(4) The seal detail, Section A-A, shown in Plate B-22, eliminates vibration problems caused by changes in the length of the leaves due to temperature fluctuations. Inherent in its higher location and orientation, it is also less susceptible to damage from debris and provides positive sealing under unbalanced head

conditions. Therefore, this type of seal is recommended for new construction.

(5) Where there are large amounts of debris, drift, and large rocks tumbling along the bottom, such as in the shallow rivers of the Upper Mississippi River System, a successful method of sealing has been attaching the J-seal to the embedded metal in the sill. This method of sealing is not easily damaged, is reliable, and can be easily replaced. See Plate B-22 for details.

(6) Above the top girder, J-type seals are used to seal the leaf to the top of the bulkhead plate. See Plate B-23 for a typical detail.

m. Miter guide. The miter guide is used to bring both leaves of the gate into the mitered position simultaneously, thereby facilitating seating of the miter blocks. The guide assembly may be located on the upstream side of the top girders or on top of the top girder web of each leaf. The miter guide is made up of two major components, the roller, mounted on an adjustable bracket, and the two-piece, adjustable, v-shaped contact block with its support. The roller bracket and the contact block are connected to their supports with a series of push-pull bolts to permit field adjustment. Steel shims or epoxy filler may be used to secure the miter guide components in their final positions. The height of the contact block should be greater than the length of the roller. The roller should be equipped with a bronze bushing and a suitable greasing arrangement. (See Plates B-19 and B-20 for typical details.)

n. Walkway. Each leaf of all miter gates should be equipped with a walkway such that when the gate is mitered a continuous walkway is formed across the top of the gate. The walkway should have a width of 4 ft 0 in. back-to-back of support angles, with the top of the walkway flush with the top of the lock wall. The vertical legs of the support angles will act as a toe board for the walkway. (See Plate B-19.)

(1) The angle is supported by vertical stiffeners and the bulkhead plate on the downstream side and by structural tees acting as columns on the upstream side. The tees should be placed above the vertical diaphragms and girder web stiffeners as far as practical. The design load for the walkway should be 100 pounds per square foot (psf).

(2) Steel grating shall be type II and hot dipped galvanized after fabrication, with a minimum depth of 1-1/4 in. The ends of all grating shall be banded with bars the same size as the bearing bars. Panels shall be made in convenient sizes for installation and removal, with a minimum of four clips per panel.

(3) Other materials may be used for the walkway surface on top of or in place of grating with an adequately designed support system. These materials should have adequate load-carrying capacity if used in place of steel.

(4) The end of the walkway adjacent to the lock wall should be made on a radius, usually 4 ft 5 in., from the center line of the gudgeon pin to the outside edge. This section should be hinged at the edge of the bulkhead plate. The outer edge of the radius is supported by an angle on the lock wall and an angle that is an integral part of the grating system over the anchorage recess.

(5) Handrail should be designed to meet OSHA Standards which require it to support a 200-pound (lb) concentrated load applied at any point in any direction. For normal installations and post spacing, 2-in.-diameter extra strong pipe post with 2-in. standard pipe rail, or equivalent aluminum if economy dictates aluminum for the lock walls, will be required. The railing should be removable and made in convenient size panels, with handrail located on both sides of the walkway. For additional information and guidance on railing design see the ASSHTO Standard Specifications for Highway Bridges.

o. Bridgeway. Instead of a walkway, a maintenance bridgeway may be provided over and supported by the lower miter gates to accommodate a mobile crane, thereby eliminating the frequent need for a floating plant for many maintenance and repair operations. The roadway and supports may be designed for the wheel loads of a 20-ton-capacity mobile crane without impact. The allowable working stresses will be in accordance with current AASHTO specifications.

p. Fenders and gate stops. All miter gates should be equipped with a system of bumpers and fenders to protect the gate from impact and to prevent damage by passing tows when the gate is in the recess. Four basic types of fender systems have been used on gates in the past, with the systems consisting of wood, rubber, metal, and a combination of rubber and metal.

(1) The all-metal type, normally made of pipe, tubing, or curved plates, offers the advantages of ruggedness and minimum damage while in use but has the disadvantage of having very little energy-absorbing capacity. Where welded directly to the girder flanges, impact is

transferred through the girder web to the operating strut, anchorage, and pintle.

(2) A combination fender, made of pipe or a curved plate, mounted with rubber pads between the metal contact surface and the girder flanges gives a more desirable energy-absorbing capacity but is a more complex and expensive system.

(3) The all-rubber fender system offers the highest degree of impact protection for the gate but has some disadvantages such as passing tows tending to tear the rubber fender from the gate and the increased cost of the system; however, low-friction butyl rubber fenders are being used successfully and may prove to be a viable alternative to timber based on a life-cycle cost.

(4) When all aspects of the basic system are considered, timber fender systems appear to be the most desirable. Timber offers a reasonable degree of resiliency for gate protection, is rigid enough to resist the sliding forces from passing tows, and is normally readily available, and in most cases, is considerably more economical than the other systems. When timber is used, white oak is generally the more desirable species if available locally. When white oak is unavailable, pine timber is an acceptable substitute. The size of timber of either white oak or pine should generally be 10 in. by 10 in. (S4S), pressure treated with creosote if pine and untreated if white oak.

(5) The fender system should be installed on the downstream flanges of all horizontal girders subject to an impact loading. Generally, this extends from a point at or slightly below the minimum pool up to a point approximately 6 ft above the maximum pool to be in the lock during operation. Consideration should be given to placing fenders 2 ft on center vertically in areas where heavier tows are likely to cause considerable damage to gates. Vertical beams spanning between horizontal girders should be used to support the extra fenders. Fenders should be fastened to the flanges of horizontal girders with a minimum of 3/4-in.-diameter bolts, 2 ft on center and alternating sides, vertically, of the flange, with the head of all bolts recessed a minimum of 1 in. to prevent passing barges and boats from catching the bolt heads. If rubber fenders are used, bolt heads should be recessed as much as practical to allow for compression of the fender and prevent the bolts from being caught by passing tows.

(6) Bumpers are selected by applying the same criteria as those for fenders. Where ice buildup in the recesses is not a problem, bumpers are fastened to the wall of the recess to cushion any impact between the gate leaf and the wall. If ice buildup in the recess is a problem, bumpers can be mounted on the gate leaf. Timber bumpers are generally made of 12-in. by 12-in. (S2S) white oak. Bumpers are placed so as to strike the leaf near the end vertical diaphragm at the miter end, on the center line of the horizontal girders. The minimum number of bumpers used should be one for each of the top two girders and one for each of the bottom two girders. On high gates, it may be desirable to also place bumpers for some of the intermediate girders. The length of the bumpers should be approximately 2 ft on the impact face. Each bumper should be fastened to the wall of the recess with a minimum of two 3/4-in.-diameter bolts, with the ends of the bolts recessed a minimum of 1 in. to prevent the bolts from striking the gate.

q. Gate latches. Latches should be provided to hold each gate leaf in the recess against temporal hydraulic loads and in case of an emergency. Due to the vertical stiffness of the leaf a latch at the top of the leaf is normally sufficient. Where the lock is used as a floodway during high flows and where required by temporal hydraulic loads, additional latches, located near the center of the leaf, vertically, or near the lower miter corner of the leaf, may be required. Latches should be so constructed that the leaf is held snug against the bumpers so the potential vibration is kept to a minimum. Also see automatic gate latches, paragraph 2-5*f*(3). A latch or tie should also be provided to tie the leaves in the miter position, again with the ability to pull the leaves together so as to reduce the probability of vibration. See Plates B-24, B-25, and B-26 for suggested latch details.

r. Embedded metals. The items normally included as embedded metals are miter sill angle, pintle base, wall quoin and support members, embedded anchorage, and gate tieback. With the exception of the pintle base, all items are usually made of structural steel, with some items, such as the wall quoin block, having a corrosion-resisting surface in some instances. All items have been discussed previously except the sill angle. The sill angle is placed in second-pour concrete, with provision for adjustment to the gate leaf, with all adjustments being made before the second pour is placed. See Plates B-21, B-22, and B-32 for a suggested plan of a sill angle arrangement.

s. Cathodic protection. Two basic methods of cathodic protection are the sacrificial anode method and the impressed current method with the impressed current system being the most efficient. Impressed current is required to protect the large areas between the horizontal girders and the skin plate of the gate. The anodes of the system are placed between the horizontal girders, with the vertical wiring passing through holes in the girder webs. This makes the system much less susceptible to damage from traffic or debris. In most cases, metallic conduit and some angle iron are required to protect the cathodic protection anodes. (See CW-16643 for impact protection.) See Chapter 7 of this manual for additional information.

2-2. Miter Gates, Horizontally Framed-Arch Type

The analysis of the arch gate is similar to that of the straight horizontally framed type gate. As with the straight gate, the general analysis for the arch neglects the vertical stiffness of the gate leaf and skin plate. Plate B-27 shows the geometry and forces on the arch rib. The longitudinal axis of the horizontal rib girder approximates the "pressure or thrust line" from the loading conditions; thus the magnitude of the bending moment in the ribs, determined from the eccentricity of the axial load to the ribs' axis, is a minimal value. The skin plate for this gate is designed as a continuous member. The intercostals of the gate shown in Plate B-28 do not come in contact with the skin plate. The primary function of the intercostals is to serve as vertical diaphragms. Design of the other elements of the arch gate leaf and anchorages is covered under paragraph 2-1. Plates B-28 and B-29 show horizontal rib girder and diaphragm layout.

2-3. Miter Gates, Vertically Framed

Horizontally framed gates provide a more rigid structure and are usually economically comparable to vertically framed gates. While vertically framed gates should not be used for new construction, this manual covers vertically framed gates to provide information because of their use in existing structures.

a. Reactions. Due to the basic framing plan of a vertically framed gate, with the horizontal girder supporting the upper end of all vertical members, the reaction of the horizontal girder is similar to the reaction of a girder in a horizontally framed gate. The girder in each type of gate acts as a segment of a three-hinged arch, with the end reactions and related forces being the same in both cases. The designations R, N, P_1, and P_2 are the same for both horizontally and vertically framed gates. The lower ends of all vertical members are supported directly by the sill, with the bottom girder acting to transfer the concentrated loads into a uniform reaction on the sill.

b. Skin plate and vertical beams.

(1) Skin plate. Existing vertically framed gates may have either the conventional-type skin plate, generally located on the downstream side of the leaf, or a skin plate composed of buckle plates fastened to the upstream flanges of the vertical beams and framing into the webs of the vertical girders. Although buckle plates are still in use on existing gates, they are no longer used for new construction. In determining the location of the skin plate for a vertically framed gate, consideration should be given to the problems of uplift and silting. While the skin plate located on the downstream face of the gate eliminates uplift, the maximum area is exposed for silt accumulation. The reverse is true for the skin plate located on the upstream face of the gate. The more desirable skin plate location will have to be determined for each site, weighing the problem of uplift against the problem of silting.

(a) The analysis of flat panels of skin plate is the same as discussed for horizontally framed gates, with the desirable panel shape being approximately square. (See Plate B-2 for additional information.)

(b) Intercostals are required for flat skin plates, spanning horizontally between vertical beams and between vertical beams and vertical girders. The criteria for intercostal spacing and design are essentially the same as those for horizontally framed gates. See Figure 2-3 for additional information on design.

(2) Vertical beams. Vertical beams span between the top and bottom girders, supporting the buckle plates on their upstream flange or the flat skin plate on the downstream flange. The vertical beams are assumed to be simply supported top and bottom, with simple moment and shear dictating beam size. Spacing of the vertical beams is determined largely by load and support requirements for the skin plate system with a normal location being at the quarter points between vertical girders.

(3) Vertical girders. Vertical girders are vertical members that function as vertical beams and at the same time serve as support members for the top and bottom girders. The vertical girders are spaced so that practically all vertical forces caused by the diagonals are carried by the vertical girders. The most effective panel for diagonals is when the height is no more than 1.50 times the width. The vertical girders and the bottom girder are normally the same depth so as to

simplify framing and make the bottom girder flanges more directly effective in taking the components of the diagonals. The stability of the girder flanges under these components should be verified, assuming the flanges to act as columns. Webs of the girders are normally determined by minimum thickness rather than by shear requirements (the minimum thickness of all material should be 3/8 in.) and should be checked for stiffener requirements.

c. Horizontal girders.

(1) Top horizontal girder. The top horizontal girder is designed to withstand a simultaneous load of water force and boat impact. The water force is applied as concentrated loads by the vertical beams and girders; the boat impact load is as described in paragraph 2-1*b*(1), acting directly on the top girder. The top girder design is essentially the same as that for the girders in a horizontally framed gate; the symbols W, N, R, P_1, and P_2 are the same for both types. The reaction of the top girder is transmitted through steel bearing blocks at each end of the girder. These blocks are similar to the bearing arrangement for horizontally framed gates, having the same convex and concave faces and the same adjustment. The bearing blocks may be of cast steel or a built-up weldment; the weldment has the advantage of being more easily obtained in the event replacement is necessary. The girders should be designed to withstand water load and basic stress or the combined water and boat impact with an allowable 1/3 overstress.

(2) Bottom horizontal girder. Under normal conditions, the bottom girder does not function as a girder but rather as a member to transfer the concentrated vertical beam and girder loads into a uniformly distributed horizontal force on the sill. For most gates, the bottom girder center line is located approximately 4 in. below the top of the sill to provide sufficient bearing surface between the girder and the embedded metal. The girder is also checked for sufficient capacity to carry the reaction from any vertical beam or girder to adjacent beam or girder points if irregularities or obstructions between the sill and bottom girder prevent bearing at a vertical beam location. The minimum effective length for this should be twice the vertical beam spacing. When the leaf is not in the mitered position, the bottom girder acts as a column, having an axial load created by the dead weight of the leaf. The downstream flange of the bottom girder is designed to distribute vertically the bearing load on the sill, which may require stiffener plates to support the flange. If the skin plate is not a flat plate on the downstream face of the leaf, the downstream flange of the bottom girder is subjected to vertical bending due to the hydrostatic uplift on the bottom of the leaf with the web of the girder acting similar to a skin plate. Adjacent to the pintle, the bottom girder should be checked for the horizontal reaction of the pintle. The depth of the bottom girder also influences the depth of the vertical girders and has a direct relation to the stiffness of the leaf, this being determined by the distance between sets of diagonals or, in the case of a flat skin plate, the distance between the skin plate and diagonals.

d. Diagonals. Design of the diagonals for a vertically framed gate is essentially the same as that for a horizontally framed gate (see USAED, Chicago 1960). Most existing vertically framed gates have diagonals on both the upstream and downstream faces, with buckle plates located between the two sets. If a flat skin plate is used on the downstream face of the leaf, diagonals are required only on the upstream face, with the skin plate taking all the vertical shear from dead load. The number of panels of diagonals used on vertically framed gates depends on the spacing of vertical girders. The panel size of height equals 1.50 times the width is desirable, but should not in itself be the only consideration for vertical girder spacing, which sets the panels for diagonals. Usually leaf dimensions are such that three sets of diagonals on a leaf face are commonly used. Due to flexibility of a vertically framed gate turnbuckles are recommended on all diagonals to allow for easier adjustment at a later time. See Chapter 3 and Plate B-17 for additional information on design of diagonals.

e. Wall quoin. The wall quoin of a vertically framed gate, similar to the wall quoin of a horizontally framed gate, serves to distribute the girder reaction of the horizonal girder. The main difference in the two types is the vertical height of the reaction bearing area. The wall quoin of a vertically framed gate is normally in the order of 2 ft-0 in. high and 1 ft-8 in. wide. The quoin block may be made of cast steel or a built-up weldment, with weldment generally being more readily available in the case of replacement. The block is made to fit the quoin block of the girder and is attached to an embedded beam to distribute the force to the concrete. The beam should be of sufficient size to maintain bearing on the concrete to approximately 600 psi or less, so that cracks in the concrete around the corner of the gate recess will be kept to a minimum. The beam is generally placed horizontally in first-pour concrete with the bearing being detachable with provisions for adjustment.

f. Top anchorage and gudgeon. The design of the anchorage elements is similar to the design of the anchorage for horizontally framed gates. Frequently the same anchorage is used for both types when a lock has an upper gate vertically framed and a lower gate horizontally framed, where the small difference in materials generally is not enough to offset the savings of making two identical sets. The gudgeon pin and hood are both similar to those for horizontally framed gates, with the exception that the pin hood of the vertically framed gate increases the moment on the vertical beam adjacent to the quoin girder. This gives a combined loading of water plus the forces from the pin hood on this particular vertical beam.

g. Strut connection. The strut connection for vertically framed gates is essentially the same as that for horizontally framed gates, with the exception that the horizontal girder for vertically framed gates carries all the strut force whereas vertical diaphragms on horizontally framed gates distribute the load to the first two and sometimes the first three horizontal girders.

h. Pintle and pintle anchorage. The design of the pintle for vertically framed gates is the same as that for horizontally framed gates, using the same procedures and materials. The design of the pintle base for vertically framed gates is essentially as described for horizontally framed gates, with similar bases being required for horizontally framed leaves consisting of five or six girders and vertically framed leaves. Relatively speaking, horizontal forces on the pintle base are greater for the vertically framed gates and the smaller horizontally framed gates. Unlike horizontally framed gates, the pintle socket, or center of pintle, is generally located on the center line of the bottom girder. See Plate B-30 for information relating to the seal between leaf and pintle base.

i. Bottom sill. The bottom sill for vertically framed gates, unlike the sill of horizontally framed gates, receives a significant amount of water force applied to the gate. The embedded metal segment of the sill should provide an adequate bearing and sealing area and limit bearing on the concrete to approximately 300 psi or less. Anchor bolts to hold the embedded metal are set in first-pour concrete with the embedded metal placed in second-pour concrete. See Plate B-32 for a typical sill layout.

j. Seals.

(1) Wall seals. The wall seal of a vertically framed gate consists of an embedded channel with a cladding of corrosion-resisting material on the exposed sealing surface. This channel is embedded in first-pour concrete, with the rubber J seal on the leaf being adjusted to the sealing surface of the channel. (See Plate B-30.) The seal on the gate leaf is composed of a rubber J seal attached to a vertical plate which is an extension of the web of the vertical quoin girder. The flange of the quoin girder is made of one plate, with the web extension welded to the outside of the flange. An angle between the rubber seal and the web extension allows for adjustment of the seal.

(2) Miter seal. The miter seal consists of a vertical plate on one leaf and a conventional J seal on the other leaf, placed so that the water pressure forces the rubber seal against the vertical plate. Below the web of the bottom girder two rectangular rubber blocks, one on each leaf, form the seal between the vertical J seal and the sill.

(3) Bottom seal. The bottom seal of vertically framed gates is formed by the contact between the bottom girder and the embedded metal of the gate sill. A metal bearing plate is attached to the downstream flange of the bottom girder and this also acts as a seal plate. At the end of the leaf adjacent to the pintle, a solid rubber block seal attached to the leaf is used between the leaf and pintle base. (See Plates B-30 through B-32 for additional information.)

k. Mitering device. The mitering device is essentially the same for both vertically and horizontally framed gates with the same basic dimensions and materials used for both types. See Plates B-19 and B-20 for a typical mitering arrangement.

l. Walkways. Walkways for vertically framed and horizontally framed gates are essentially the same, using the same basic dimensions and design criteria. See paragraph 2-1*n* on walkways for horizontally framed gates and Plate B-19 for additional information.

m. Fenders and gates stops. The same protection system and gate stops are used for both vertically and horizontally framed gates. See paragraph 2-1*p* for more information.

n. Gate latches. Gate latches for both vertically and horizontally framed gates are essentially the same. While there may need to be a slight variation in the method of attaching the latching unit to the leaf the same general method should be used for the vertically and horizontally framed gates.

o. Embedded metals. The normal items included in the category of embedded metals are the embedded top anchorage, quoin bearing, pintle base, and miter sill embedded metal. All items are essentially the same as those for horizontally framed gates except the miter sill embedded metal. All other items have been discussed in the paragraphs on horizontally framed gates and in previous sections for vertically framed gates. While the sill embedded metal is similar for both horizontally and vertically framed gates, the sill for vertically framed gates is designed to receive the gate reaction and distribute this force to the concrete. As previously stated, the sill embedded metal serves two functions, acting as a bearing surface and as a sealing surface. The embedded metal is placed in second-pour concrete; the supporting anchor bolts are set in first pour. All adjustments between gate and sill are made before placing the second-pour concrete. See Plate B-32 for a suggested sill layout.

p. Cathodic protection. The cathodic protection systems of both vertically and horizontally framed gates are essentially the same. The location and number of anodes may vary but the method and components are the same for both types of gates. For further information, see Chapter 7.

2-4. Erection and Testing, Miter Gates

a. Miter gates, both horizontally and vertically framed, should be completely shop assembled, if size permits, with adjoining pieces fitted together to ensure satisfactory field connections. The tolerances should not exceed 1/16 in. for individual members up to 30 ft in length and not more than 1/8 in. for members over 30 ft in length. Structures made from two (2) or more members should not deviate from the overall dimension by more than the tolerance for any one member. Rubber seals should be fitted and assembled to the gate leaf in the shop, with holes drilled to match the seal supports on the gate leaf and then removed for shipment. Before disassembly of the leaf each piece should be match-marked to facilitate erection in the field.

b. The bottom pintle casting shall be adjusted to proper elevation and position and then properly concreted in place before erection of the leaf. The bearing surface of the pintle and bushing should be thoroughly cleaned and lubricated before setting in place. Consideration should be given to using temporary concrete pedestals to support the leaf, with a minimum of two pedestals per leaf and allowing the pintle to support the quoin end of the gate leaf.

c. Care should be taken to ensure that the parts of the gate leaves are in correct alignment before any field welding is commenced. All necessary precautions should be taken to prevent distortion of the leaf as a whole or of any of its components. Each unit should be accurately aligned so that no binding in any moving parts or distortion of any members occurs before final connections are made.

d. After completion of the leaf, the top anchorage links should be installed and adjusted so that the center of the gudgeon pin is in vertical alignment with the center of the pintle.

e. After diagonals have been prestressed and final adjustments have been made to the anchorage, the leaves shall be mitered and securely held in this position while the contact blocks at the quoin and miter ends are brought into firm contact by adjusting the bolts behind the blocks. After adjustment of the blocks, the leaves should be swung out and zinc or epoxy filler poured between the seal blocks and the end plates of the leaves. If zinc is the option selected by the contractor, blocks and plates adjacent to the zinc shall be preheated to a temperature between 200 and 250 deg F, immediately preceding the pouring to prevent the zinc from cooling before it can fill the area behind the blocks. The pouring temperature of the zinc shall be maintained between 810 and 900 deg F to avoid volatilizing or oxidizing the metal and to ensure that it will fill the area behind the blocks. Pouring holes should be located 2 to 3 ft apart. If the alternate backing of epoxy is selected, the material should meet the properties set forth in paragraph 2-1*k*(4).

f. After a gate leaf is erected, diagonals prestressed, and miter and quoin blocks adjusted and set, each leaf should swing without interference of the quoin blocks until, as the gate is mitered, the quoin block on each leaf makes tight contact with the one on the lock wall. After final adjustment of blocks and seals, the gate leaf should swing freely and any point on the moving structure should remain in a horizontal plane throughout the entire range of movement. Past experience indicates that 1/16 in. on the smaller locks to 1/8 in. on the 110-ft or larger locks can be allowed as maximum variance from the horizontal plane and not have any adverse effect on the gate, although every effort should be made to keeping the leaves in a horizontal plane.

g. After completion of the gate, including prestressing of the diagonals, installation of all seals, and all adjustment, the gate leaves should be swung through a sufficient number of opening and closing operations to assure that the leaves are in true alignment and that necessary clearances have been provided. After this trial operation the leaves should be swung out and the second-pour concrete placed in the sill and wall quoins.

h. The miter guide should be installed after the trial operation and second-pour concreting has been completed. The guide bracket and roller bracket assemblies should be mounted on their respective leaves with the gate in the mitered position. Adjustments should be made to the brackets so that either leaf may be mitered or opened without disturbing the other leaf.

i. The final test on the gate should consist of operating the gate under power, by means of the permanent operating machinery, first during the unwatered condition and then using available headwater and tailwater. The leaves should be operated through their entire travel a sufficient number of times to indicate that all parts and equipment are in proper operating condition. The workmanship in fabrication and erection of the gates shall be such that, when mitered, they will form a watertight barrier across the lock under all ranges of head, except for minor negligible leakage at the miter, sill, or quoin.

2-5. Operating Machinery

a. General description of linkages and components. Four different types of miter gate operating machines have been frequently used. The Panama Canal linkage, which has no angularity between the strut and sector arms at either the open or closed positions of the gate, is shown in Figure 2-6. The Ohio River linkage, having angularity between the strut and sector arms at both the open and closed positions, is shown in Figure 2-7. The Modified Ohio River linkage has angularity between the strut and sector arms at the recess or open position and no angularity at the mitered or closed position. This linkage is shown in Figure 2-8. A direct connected cylinder has been used on some 84-ft-wide locks and consists of a hydraulic cylinder and rod connected to a pin on the gate and a pin on the lock wall, the piston force being transmitted directly from the piston rod to the gate. This linkage is shown in Figure 2-9.

(1) Panama Canal linkage. The Panama Canal linkage has been used primarily where electric motor operation was feasible, that is, at locations where high water will not overtop the lock wall. The operating machinery for this linkage generally consists of a high torque, high slip a-c motor driving the gate through two enclosed speed reducers, bull gear, sector arm, and spring-type strut. This linkage will permit the gate to be uniformly accelerated from rest to the midpoint of its travel and then uniformly decelerated through the remainder of its travel, thus eliminating the need for elaborate motor speed control. This is accomplished by locating the operating arm and strut on “dead center” when the gate leaf is in both the open and closed positions. The strut must be located at a higher elevation than the sector arm in order to pass over the arm and become aligned for dead center position when the gate is fully open. Special consideration should be given to the design of this eccentric connection between the strut and sector arm. An assembly layout of the Panama-type linkage is shown in Plate B-47.

(2) Modified Ohio linkage. The Modified Ohio linkage is similar to the Panama type except that the dead center alignment is attained only in the gate fully closed position. With the Modified Ohio linkage, the strut and sector gear are located at the same elevation, thus eliminating the eccentric strut connection but preventing the linkage from attaining the dead center position with the gate recessed. The operating machinery for this linkage has been built either for electric motor drive as with the Panama linkage or hydraulic operation as with the Ohio River machine. An assembly layout of the Modified Ohio linkage with electric motor drive is shown in Plate B-48.

(3) Ohio linkage. The Ohio linkage consists of a hydraulic cylinder, piston rod, toothed rack meshed with a sector gear, and a sector arm, the spring-type strut being connected to the gate leaf and sector arm. A typical machine is shown in Plate B-49.

(4) Direct connected linkage. Another type of machine is the “Direct Connected Type.” It consists of a cylinder mounted in a gimbal bracket and located in a recess on the lock wall with the piston rod connected directly to a bracket on the gate. The kinematics of this linkage is such that it is necessary to control the acceleration of the gate by use of a variable volume pumping unit instead of relying on the mechanical advantage of the linkage to accomplish this. Since the piston rod is used as a strut, it is generally a little larger in diameter than the rod of the Ohio-type machine. This larger rod increases the ratio of time of opening to time of closing since the net effective cylinder volume on the rod end is smaller than the volume on the head end. This variation in opening and closing times can be eliminated by use of

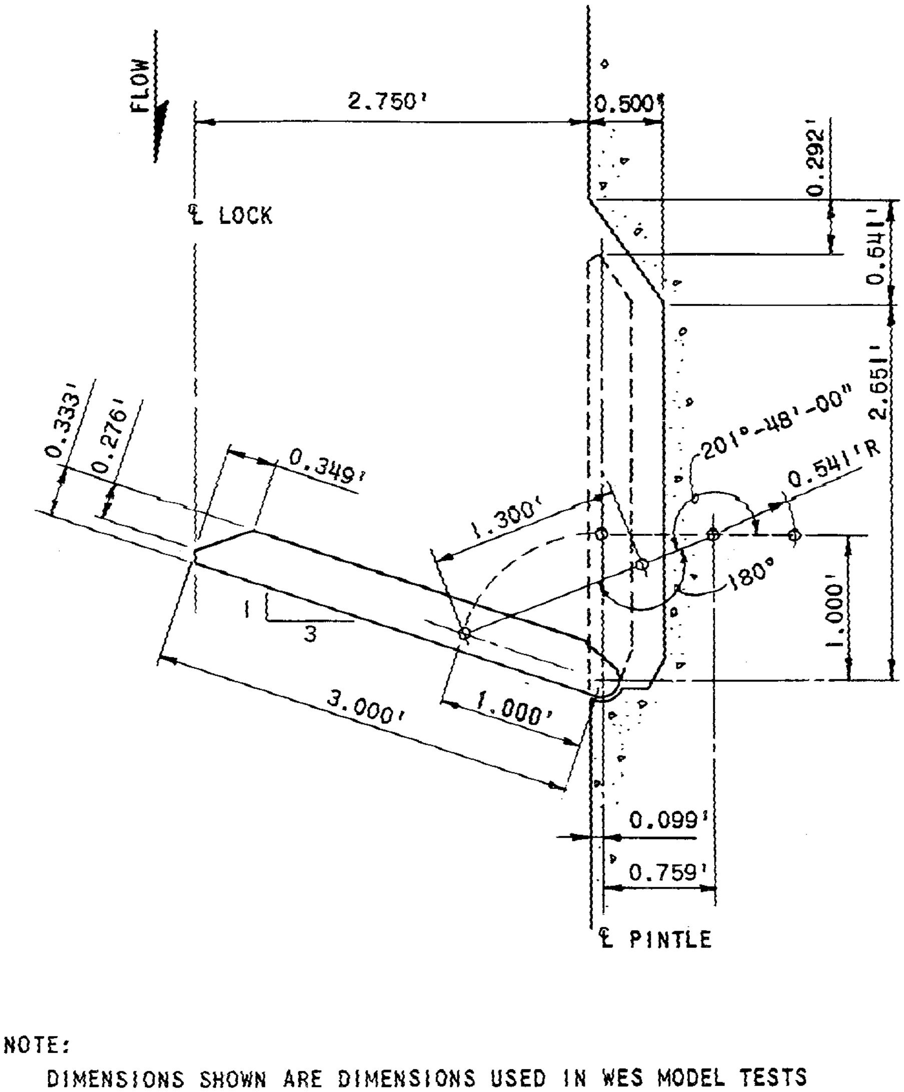


Figure 2-6. Panama Canal linkage (USAEWES 1964)

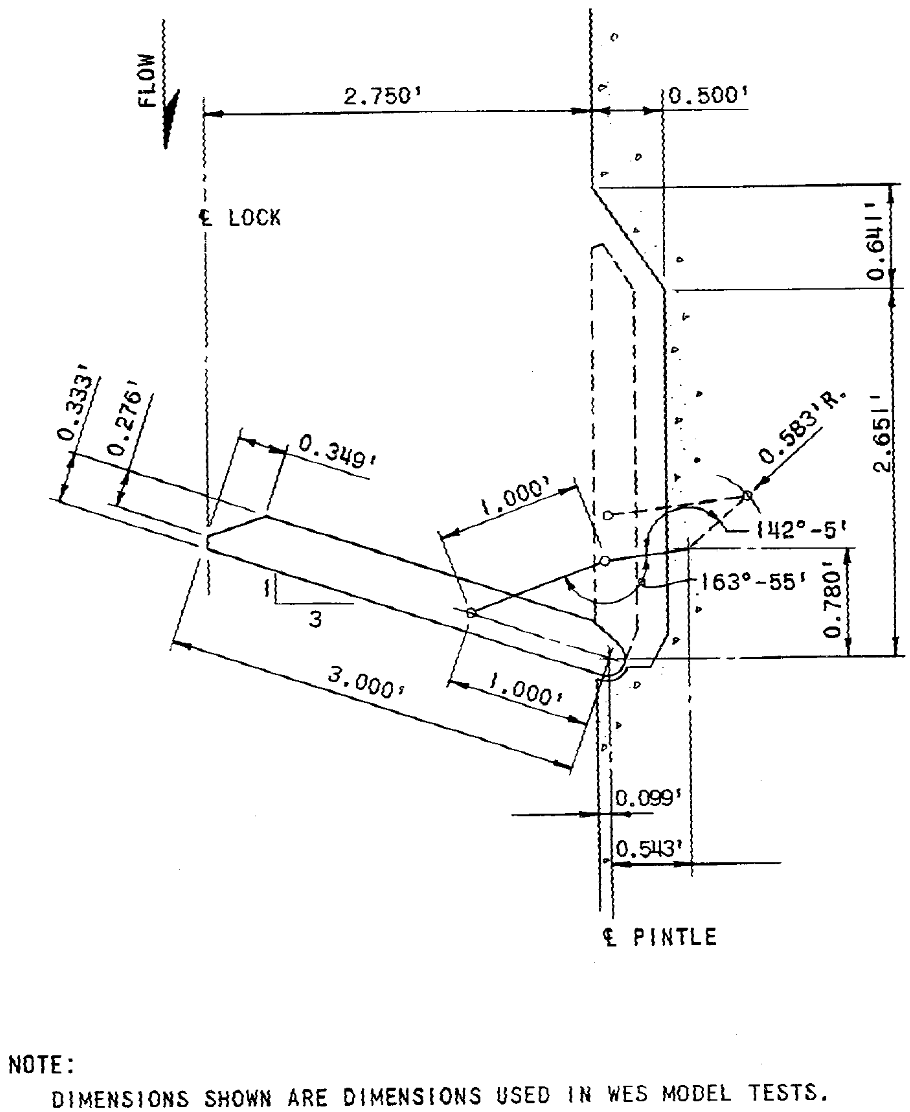


Figure 2-7. Ohio River linkage (USAEWES 1964)

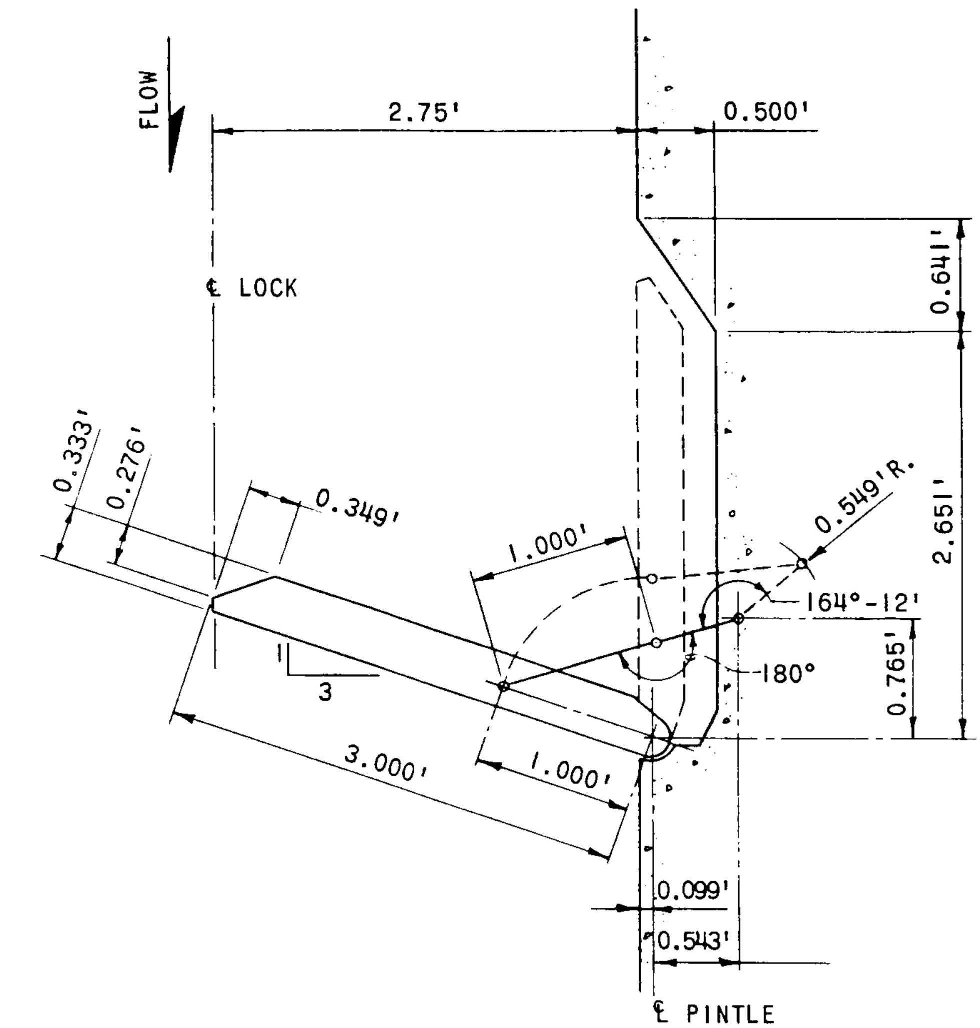


Figure 2-8. Modified Ohio River linkage (USAEWES 1964)

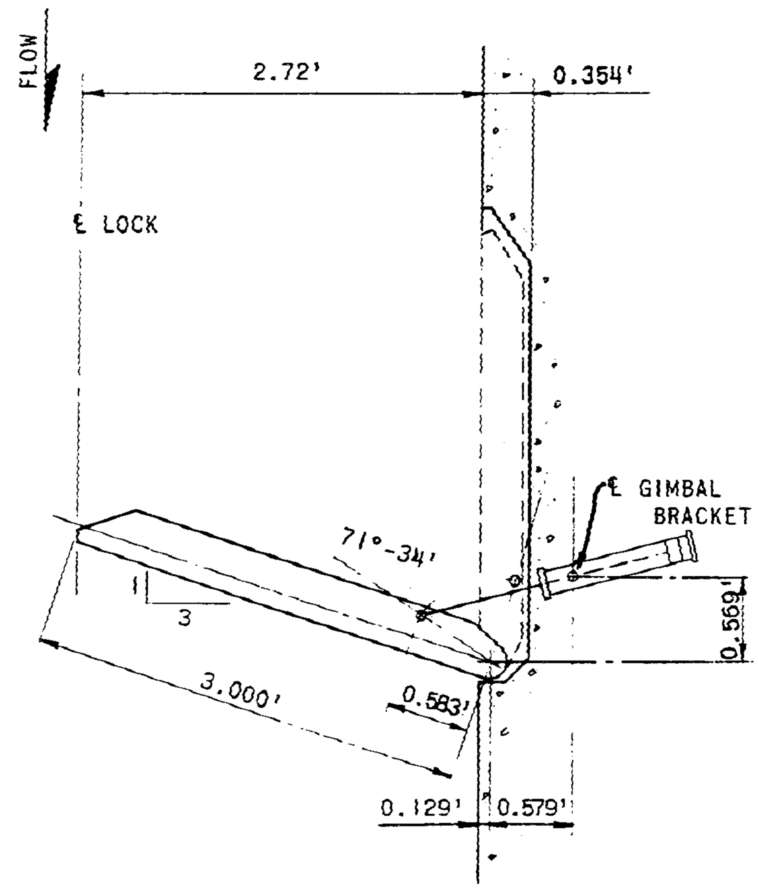


Figure 2-9. Direct connected linkage

variable volume flow control valves or by use of a regenerative circuit along with a cylinder in which the rod area is about one-half the piston area. The arrangement of the direct connected type machine is shown in Plate B-50. The direct connected type of machine has been used satisfactorily on 84-ft-wide locks in the U.S. with locks up to nearly 100 ft and 110 ft wide in Europe. The use of the direct connected cylinder on locks 110 ft wide now appears to be a viable option; however, an in-depth design analysis should be made for each application considered. Experience has shown that the direct connected machine costs approximately 30 percent less than the conventional Ohio-type machine when used on locks up to 84 ft wide.

(5) Recommended linkage. The Ohio River or direct connected linkage is probably the most satisfactory type to use with hydraulic cylinder operation. With the Ohio River and Direct Connected linkages, load analysis for all components is possible. Overloads due to surges or obstructions are carried through the piston and converted to oil pressure which is released through a relief valve. In this way, all machinery component loads can be determined based on the relief valve setting. This is also true for the Modified Ohio linkage except at the mitered position. As this linkage approaches the mitered position, the sector arm and strut approach the dead center position. Should an obstruction be encountered at this time, the force in the strut becomes indeterminate. Although this linkage provides restraint against conditions of reverse head in the dead center position, it must be designed with an easily repaired “weak link” to limit the maximum loads that can be placed on the machinery components. The Modified Ohio River linkages on some locks have yielded unsatisfactory results, and these have been converted to Ohio River linkages. The Ohio River linkage offers several obvious advantages due to its unique geometric configuration relating to the

acceleration and deceleration of the miter gates. The disadvantages of this system are wear, bearing forces, and mechanical inefficiencies associated with the geared rack, sector gear, sector arm, and strut. Ohio River linkages have recorded a service life of over 50 years on many locks, with good reliability and a minimum of maintenance.

(6) Struts. Two types of struts have been used for the above-mentioned machines. One type utilizes several nests of helical coil springs installed into a cartridge and attached to a wide flange structural steel fabricated member. The springs, when compressed, act as a shock absorber to soften the loads transmitted to the operating machinery. In the case of electric-motor-operated machines, the compression in the springs permits the operation of a limit switch to cut off current to the motor when the gates are mitered or recessed. The switch also serves as a limit switch to protect the machinery against the possibility of extremely high loads which might occur if an obstruction is encountered when the strut approaches dead center in either direction. The limit switch is set to open the motor circuit at a point immediately preceding the maximum spring compression in the strut. This type of strut is shown in Plate B-51. Another type of strut utilizes a spring cartridge housing and tubular steel strut. Ring springs are used in the spring cartridge to provide the necessary deflection. Excessive maintenance and repair costs have occurred with the use of this type of strut. In addition, ring springs are available only from one manufacturer. Use of the ring-spring-type strut is not recommended. Recently, Belleville springs have been utilized in struts and appear to function satisfactorily. The Belleville spring strut is shown in Plates B-52 and B-53.

(7) Sector gear anchorage. The sector gear support and anchorage is one of the more critical items to be considered in the design of miter gate machinery. For proper machine operation and long component life, the sector gear must be maintained in rigid and proper alignment. The recommended arrangement consists of a sector base anchorage, sector base support, and a sector base. The sector base anchorage is a welded steel frame embedded deep in the concrete which provides anchorage and alignment for post-tension rods. The sector base support is a heavy, rigid, welded steel member which is anchored to the concrete by the post-tension rods. The sector base is a heavy steel casting which is bolted to the sector base support and contains the sector pin on which the sector gear turns. The sector gear pin should be restrained to prevent rotation in the sector base. The design is such that the final post-tension rod force is enough to resist the horizontal sector pin load by friction between the concrete and sector base support. In addition, compression blocks are welded to the bottom of the sector base support to provide additional resistance to horizontal motion. Details of this anchorage are shown in Plate B-49.

b. Design criteria.

(1) Design loads.

(a) Normal loads. Gate operating machinery should normally be designed to conform to the following criteria: Operating loads on the miter gate machinery should be derived by hydraulic similarity from test data obtained from model studies. The model study available for design is included in Technical Report 2-651 (USACE-WES 1964). (This was the last study made by WES on this subject.) This report includes data on the Ohio River, Modified Ohio River, and Panama Canal type linkages. The study contains necessary data for conversion to prototype torque for all three of the different types of linkages. For direct connected type machines, prototype tests were made at Claiborne Locks and results of the tests are included herein for the determination of gate torque for any proposed direct connected lock machine of similar proportions. A curve of gate torque plotted against percentage of gate closure has been included so that torque at any other submergence or time of operation can be computed by application of Froude's law, adjusting the submergence and time to suit the new conditions.

(b) Temporal loads. In addition to the above-normal loads, the miter gate machinery should be designed to withstand the forces produced by a 1.25-ft (exceeding 30-sec duration) surge load acting on the submerged portion of the miter gate. For this case, the machinery must be designed to maintain control over the miter gate when the gate is in the miter position. In the recess position, control of the gate may be accomplished by automatically latching the gate in the recess. Normal machinery operating loads govern the machinery design for the intermediate positions.

(2) Operating time. A time of operation should be selected and should be based on the size of gate. For smaller gates (84-ft lock) an average time of 90 sec should be used and for the larger gates (110-ft locks) an average time of 120 sec would be suitable.

(3) Submergence. The design of the gate operating machinery should be based on the submergence of the

upper or lower gate, whichever is greater. The design should be the same for all four gate machines since there would be no savings in designing and building two different size machines. The increased design cost would offset the reduced cost of the material used in constructing the smaller machine.

(a) The submergence of the gate is the difference in elevation of the tailwater on the gate and the elevation of the bottom of the lower seal protruding below the gate. A submergence selected for design of the gate machinery should be the tailwater on the gate that would not be exceeded more than 15 to 20 percent of the time.

(b) The operating cylinder size should be selected to provide a force to operate the gate under these conditions utilizing approximately 900 to 3,000 psi effective pressure where a central pumping system is used. If higher than 1,000 psi is selected for the operating pressure, then measures to eliminate hydraulic shock should be considered because of the long hydraulic lines. Where local pumping units are used, an operating pressure of 1,500 to 3,000 psi will be satisfactory.

(c) The time of gate operation will automatically be lengthened when the required gate torque exceeds the available gate torque. This condition may occur during starting peaks or periods of higher submergence. This condition causes the pressure in the hydraulic cylinder to rise above the relief valve setting, which in turn reduces oil flow to the cylinder slowing down the gate and reducing the required pintle torque. This increases the total time of operation; however, this slower operation will be experienced for only 15 to 20 percent of the lock total yearly operating time.

(d) Peak torque can be reduced by nonsynchronous operation of the gate leaves. A considerable reduction in peak torque can be obtained by having one leaf lead the other by approximately 12.5 percent of the operating time. The time of opening would be increased by the amount of time one gate leads the other. It has been found that in actual practice very few gates are operated in this manner.

(4) Under gate clearance. Model tests revealed an increase in gate torque values as the bottom clearance decreased, regardless of the length of operating time. When using model similarity to compute gate loads, an adjustment should be made in accordance with model experience. Normally 2.5-ft to 3.5-ft clearance under the gate should be satisfactory.

(5) Machine components. General design criteria applicable to the various machine components are presented in paragraph 1-9. Allowable stresses may be increased one-third for temporal loading conditions.

c. Load analysis.

(1) Normal loads. Normal operating hydraulic loads on miter gates are primarily caused by submergence, speed of gate, and clearance under gate.

(a) Technical Report 2-651 (USAEWES 1964) indicates that the maximum torque recorded as the gate leaves entered the mitered position (closing) varied as the 1.5 power of the submergence; and the maximum torque recorded as the gate leaves left the mitered position (opening) varied as the 2.1 power of the submergence for the Ohio Linkage.

(b) For the Modified Ohio linkage, Technical Report 2-651 indicates that the maximum torque recorded as the gate leaves entered the mitered position (closing) varied as the 1.9 power of the submergence; and the maximum torque recorded as the gate leaves left the mitered position (opening) varied as the 2.2 power of the submergence.

(c) For the Panama-Type linkage, Technical Report 2-651 indicates that the maximum torque recorded as the gate leaves entered the mitered position (closing) varied as the 1.5 power of the submergence; and the maximum torque recorded as the leaves left the mitered position (opening) varied as the 1.7 power of the submergence.

(d) The report indicates that the maximum torque recorded decreased as the 1.0 power of the operating time for both the closing and opening cycles when using the Ohio Linkage.

(e) For the Modified Ohio linkage, the report indicates that the maximum torque recorded decreased, as the 1.1 power of the operating time for the closing cycle and as the 1.5 power for the opening cycle.

(f) The report indicates for the Panama-Type linkage that the torque decreased as the 1.1 power of the operating time for the closing cycle and as the 1.3 power for the opening cycle.

(g) Tests reveal that an increase in gate torque occurs when the clearance under the gate leaf is decreased regardless of the length of operating time. Data from these tests are presented in Figure 2-10 and indicate the percentage increase in model torque for various bottom clearances relative to the torque observed with a 3-in. bottom clearance. These data can be used to adjust the observed torque values determined for a model bottom clearance of 3 in. when gate length is 3 ft.

(h) Nonsynchronous operation of miter gates results in slightly lower forces on the leading leaf. Forces on the lagging gate leaf are greater during most of the closing cycle and less during the opening cycle than similar forces recorded for synchronous operation of the gate leaves. The greatest reduction in torque appears to be when one gate is leading the other by approximately 12.5 percent of the total operating time.

(i) Barges in the lock chambers are found to have negligible effect on gate operating forces.

(j) The chamber length affects the gate torque in that the longer the chamber, the less the torque. As the length of time is increased, the less the chamber length affects the gate torque. Insufficient data are available to set up any definite adjustment factors for correcting for chamber length.

(k) Torque caused by gate pintle friction is of small magnitude and should not be considered in load calculations.

(l) When computing operating torque for a direct connected type miter gate drive, the curves shown in Plate B-87, Sheets 5 and 7, may be used. The curves are results of prototype tests made on Claiborne Lock and show gate torque plotted against percentage "closed." The torque from these curves may be adjusted to suit new conditions by the application of Froude's law as described in detail in paragraph 2-5*d* below. Since the curves were based on the use of a three-speed pump to slow the gate travel at beginning and end of cycle, it will be necessary to make similar assumptions on the proposed lock. Assuming a fast delivery rate of the pump at 1.0, the medium delivery rate should be 0.8 and the slow rate adjusted to 0.3 of the fast rate. A normal cycle would be to operate 10 percent of the gate angular travel at 0.3 capacity, 10 percent at 0.8 capacity, 60 percent at 1.0 capacity, 10 percent at 0.8 capacity, and 10 percent at 0.3 capacity. A comparison study made between this type of operation and the Panama-type linkage indicates that the direct connected machine, if operated as stated above, will compare favorably with the Panama machine in angular gate velocity (degrees per second) at all positions. If one assumes that the angular velocities compare with the Panama-type machine, the maximum torque will vary as the 1.5 power of the submergence (closing) and 1.7 power of the submergence (opening). The operating time should vary as the 1.1 power for closing and the 1.3 power for the opening cycle.

(2) Temporal loads. Temporal hydraulic loads or surges are temporary changes in water level resulting in a differential water level on opposite sides of a lock gate. These surges or differential heads may be caused by overtravel of water in the valve culvert during filling or emptying, wind waves, ship waves, propeller wash, etc. Depending on the circumstances, this differential has been observed to vary from 1 to 2 ft. These forces do not affect the machinery power requirements, but they do affect the design of the gate machine components when the gate is at the recess or mitered position. These forces have been known to fracture gate struts and shear sector pins. See paragraph 2-5*b*(1)(b) for the description of these loads.

d. Determination of machinery loads.

(1) Normal loads. Normal miter gate operating machinery loads are difficult to determine and should, whenever possible, be determined from model or prototype tests. Data compiled by the Special Engineering Division of the Panama Canal Zone taken from tests made on the existing locks and a model for the third locks and model studies included in Technical Report 2-651 (USAEWES 1964) appear to be the most reliable sources for obtaining miter gate machinery loads available at this time. When using data from the model tests, it will be necessary to adjust the data on the basis of the scalar ratio between the model and the proposed lock. The length of the gate leaf is normally used for determining the scalar ratio. From the scalar ratio, Froude's law comparing prototype to model would be as follows:

$$\text{Scalar ratio} = \frac{\text{length of prototype leaf}}{\text{length of model leaf}} = L_R \qquad (2\text{-}9)$$

Volume, weight, and force $= (L_R)^3{:}1$

Time and velocity $= L_R{:}1$

Torque $= (L_R)^4{:}1$

When using machines having the Ohio linkage, the Modified Ohio linkage, or the Panama-type linkage, the forces on any size miter gate may be obtained from

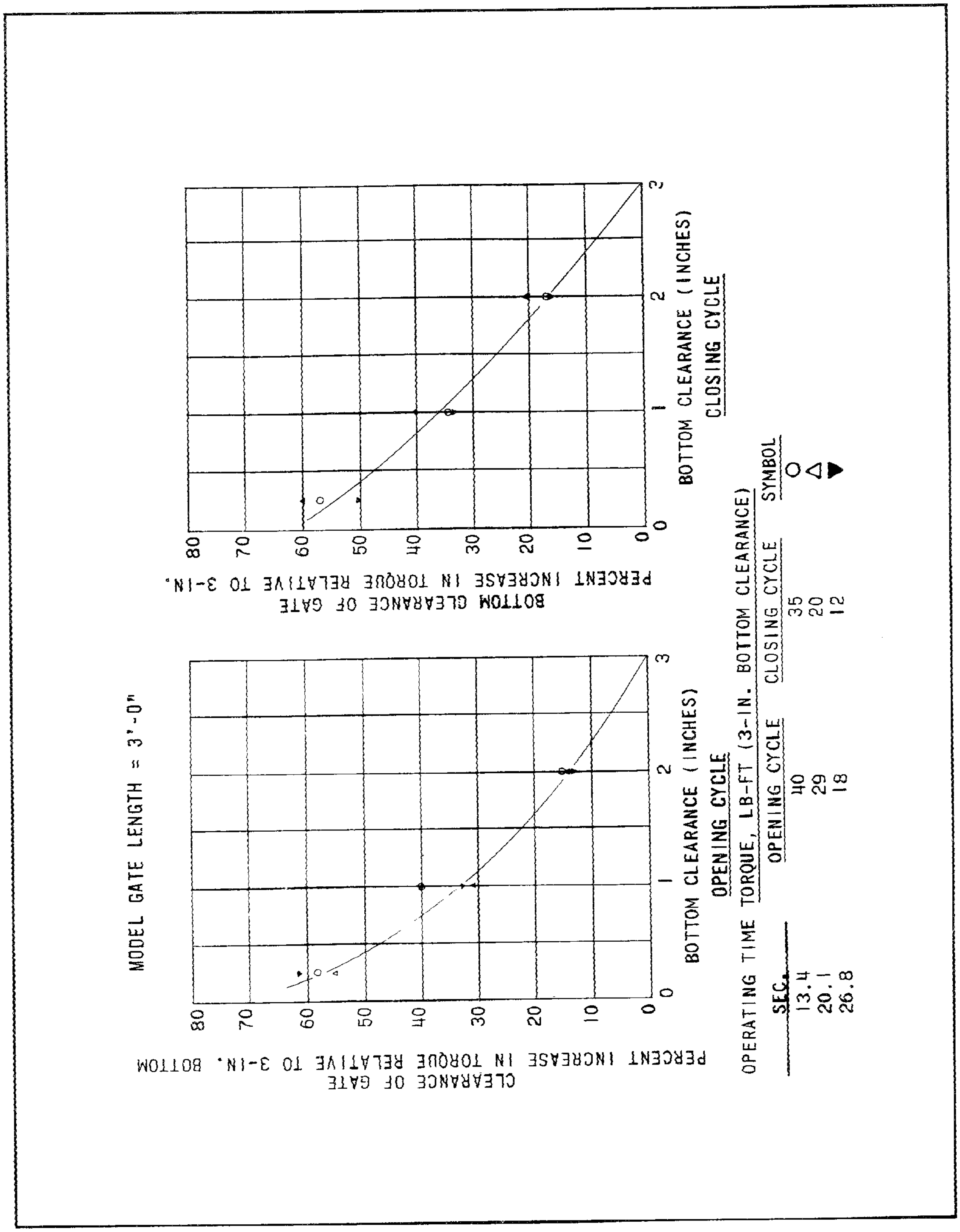


Figure 2-10. Relative effect of gate bottom clearance on torque, 4.0-ft submergence

curves shown in Plates B-83 through B-86 which are plotted from the results of the WES and Panama Canal Model Tests. Readings from the curves must be factored according to Froude's law for submergence, time of operation, and clearance under gate. Curves are based on lock lengths of 600 ft or greater. Forces for shorter lengths would be slightly greater; however very few, if any, locks would be built with chamber lengths less than 600 ft.

(a) Computation of pintle torque for Panama Canal and Ohio-type linkage. If the proposed lock gate is in the same scalar ratio with respect to length of gate and the submergence and time of operation as shown on curves and the type of linkage are the same, the pintle torque would equal the pintle torque at each position indicated on the curves multiplied by the ratio of gate leaf lengths to the 4th power.

$$P_1 = P(L_1/L)^4 \tag{2-10}$$

where

P_1 = pintle torque of proposed lock gate at selected position

P = pintle torque shown on curve of model study at selected position

L_1 = leaf length, pintle to miter end, proposed lock gates

L = leaf length, pintle to miter end for curves that have been plotted on model study

In the event the ratios of gate lengths L_1/L, submergence S_1/S, and the square of the time of operation T_1/T are not of the same scalar ratio, the formula should be expanded as follows:

$$P_1 = P(L_1/L)^4(S_1/2)^x(T_2/T_1)^y \tag{2-11}$$

where

P_1, P, L_1, and L = same as in Equation 2-10

S_1 = submergence of proposed lock gate

S = actual submergence of model gate upon which curves are based

S_2 = adjusted submergence of model lock gate $= S(L_1/L)$

T_1 = time of operation of proposed lock gate (See arc of travel adjustment below.)

T = actual time of operation of model gate upon which curves are based

T_2 = adjusted time of operation of model lock gate = $T\sqrt{L_1}\,/L$

x = power to which submergence must be raised, for particular type linkage

y = power to which time must be raised, for particular type linkage

NOTE: If only one ratio for either submergence or the square of the operating time is not of the same ratio as gate leaf length L_1/L, then only the ratio not in agreement with L_1/L need be considered in the equation.

If the arcs of gate travel differ from that shown on model curves, it will be necessary to adjust the operating time of the proposed lock T_1 to use in Equation 2-11 as follows:

Let T_A = adjusted operating time

or

$$T_A = T_1 \frac{(\text{arc of travel, proposed lock})}{(\text{arc of travel, on model curves})} \tag{2-12}$$

$$= T_1(K_1/K)$$

T_A must be substituted in equation for T_1

Use of Equations 2-10 through 2-12 results in a pintle torque which makes no allowance for motor slip since all of the model curves were based on uniform speed of hydraulic cylinder or constant rpm of the motor. If a portion of the required gate torque curve overloads the motor, the resulting time of gate operation would be slower, which in turn would result in lower gate torque during this period. The same would occur when operating the gates with a hydraulic cylinder. Overloading the cylinder would result in some of the oil being bypassed through relief valves which in turn would slow down the gate during the overload period. When using the Ohio-type linkages and torque data from Technical Report 2-651, the pintle torque P_1 should be adjusted for undergate clearance in addition to submergence and time. The percentage increase can be obtained from curves in Figure 2-10. Where a proposed lock is not subjected to flooding, electric motor operation with Panama-type or Modified-Ohio-type linkage may be considered. A high-torque, high-slip motor should be used and should be selected so that the normal full load torque available would not be exceeded by the required torque of the machine more than 15 to 20 percent of the time. Peak torque during the overload period should not exceed 150 percent of full load torque. This can be determined by plotting the required torque based on curves computed from model tests described above and by plotting available motor torque curves at various degrees of slip and superimposing these curves over the required curves. Typical calculations for determining loads using the Ohio-type linkage (hydraulic operation) are shown in Plate B-79. Calculations for determining loads using the Panama-Canal-type linkage (electric motor operation) for the same design conditions are shown in Plate B-80.

(b) Computation of pintle torque for direct connected linkages. The kinematics of this type of machine should be developed so as to provide the shortest practicable piston stroke. This will require the gate pin connection to be located out from the pintle a distance of 20 to 25 percent of the gate length, and the center line of the cylinder gimbal bracket to be located so as to give the best effective operating arm about the pintle at each position throughout the entire stroke of the piston. With use of this linkage and a uniform traveling piston, gate angular velocity will be greatest at the extreme closed or open position of the gate. Uniform travel of the piston is therefore undesirable, and it will be necessary to slow down the speed of the piston near the closed and open positions by use of a variable volume pump in the oil circuit. By slowing the travel near open or closed position of the gate, angular travel rates will be comparable with the Panama Canal linkage. Figure 2-11 shows comparison curves for angular velocity of gate plotted against percent "closed" for Panama Canal Third Locks linkage and for Claiborne Lock direct connected linkage with and without variable speed control. Time of operation should be selected for the proposed lock that will give angular gate velocities approximately equal to the velocities shown on the curve for Panama Canal. Gate pintle torque should then be taken from the prototype curves shown in Plate B-87, Sheets 3 and 5, and adjusted by means of Froude's Law of Similarity to the submergence and time requirements of the proposed lock using the same exponents as used for the Panama Canal linkage. Load computations for a direct connected machine are shown in Plate B-87, Sheets 1-10.

(2) Temporal loads. The resulting machinery loads for the case of temporal loading are based on a 1.25-ft differential head superimposed on the normal gate submergence. These loads are considered applicable only when the gate is at either the miter or recess position. In operation, these forces are resisted by a hydraulic load brake rather than by pumped oil pressure at the miter position. This is done by automatically engaging a high pressure hydraulic relief valve at the position of travel where these loads occur. For this load condition, a 33.33 percent overstress is allowed for component design. In the recess position, this load is resisted by automatically latching the gate. Only the sample computations for the Ohio-River-type machine shown in Plate B-79, Sheets 1-12, include the temporal load computations.

e. Operating machinery control.

(1) Hydraulically operated machines. A complete description of the two basic types of hydraulic systems for locks along with pertinent hydraulic system design criteria are presented in paragraph 1-11*j*. Control of these systems has utilized manual, solenoid controlled, pilot operated, and cartridge valves.

(a) With manual control, a small control stand is located over a recess on one lock wall near the gate machinery and is equipped with control valve operating levers. A schematic piping diagram of a manually controlled "central pumping" system is shown in Plate B-61. This diagram includes the connections for the tainter valves and shows the complete lock operating hydraulic system.

(b) Recent control systems utilize solenoid-controlled pilot-operated four-way and solenoid-controlled cartridge valves to control the flow of oil to cylinders. This makes the system more flexible and enables the inclusion of an electrical interlock between the miter gates and lock fill and empty valves so that the lock chamber water level cannot be changed before all gates are closed. Changing the water level in the lock chamber before the gates are closed creates a swell head on the partially closed gates which could cause them to slam shut damaging the gate and/or gate machinery. This type of control is recommended rather than the manual control. A schematic

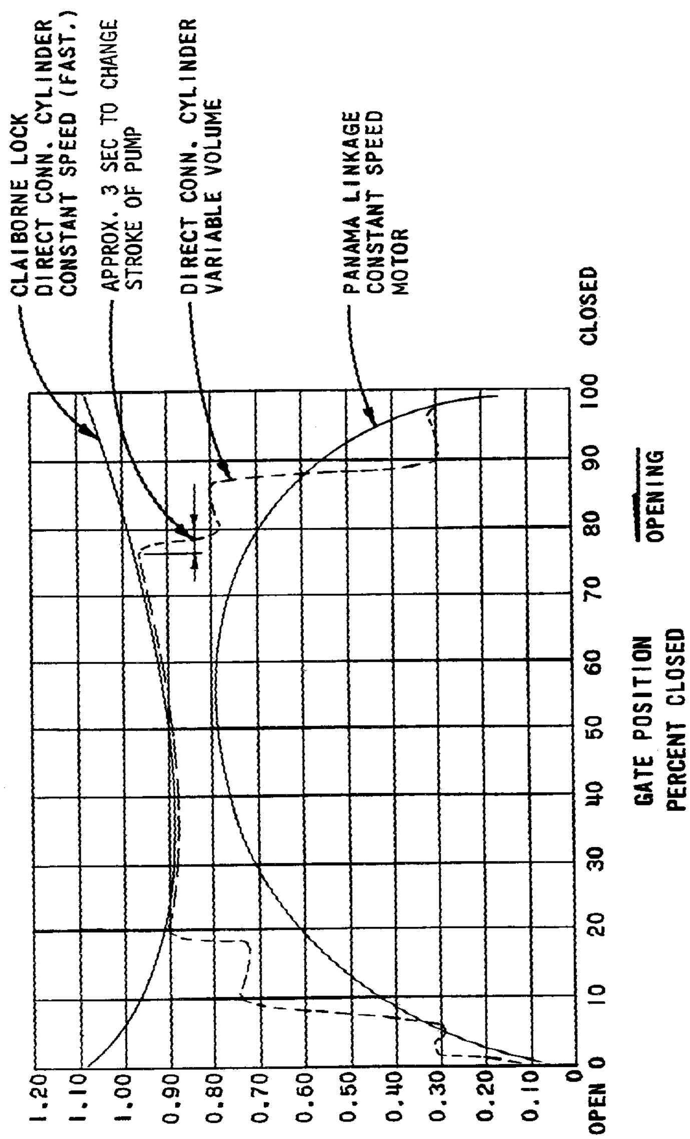


Figure 2-11. Gate velocity comparison curves

piping diagram of this control system is shown in Plate B-62. (See also Plate B-63.)

(c) The majority of locks using electrically operated directional control valves have two points of lock control (one located near each gate in a control booth). Some recently designed locks have utilized a single point of control located in the control building. Each control point consists of a control console with all the control features associated with a normal lockage. These features include valve control, bubbler system, lock lighting, navigational signal, maintain pressure, and alarms. At some projects with dual control points, the control consoles may become inundated during high water and, therefore, should be designed so that they are located above the anticipated high water (by elevating the control booths) or so that they can easily be removed. A control console layout is shown in Plate B-69.

(d) Locks with single points of control have their gate and valve control console located in the control building near the upstream gate. So that the operators can view the downstream gate during opening and mitering, a multicamera closed circuit television system is also provided. A simplified control stand is provided near the downstream gate for the operation of the gate if the television system becomes inoperative or during periods of maintenance. Means for disconnecting or transferring control from this control stand when not in use should be provided.

(e) Whether single or dual control points are utilized, the control features are the same. This system provides two speeds for miter gates and two speeds for culvert valves. This scheme also provides a high degree of automation and protection against misoperation. Electrical interlocks are used in the control circuit to produce the desired operating sequence. Limit switches located at the miter point of the gates, in the gate machinery recesses and the culvert valve recesses, are used to prevent the upstream culvert valve from being opened when the downstream gate and/or valves are open and vice versa. These interlocks are also used to prevent slamming of the gates or changing the lock chamber water level when gates are mismitered. One miter limit switch is located near the top of the gate and two miter limit switches are located near the bottom of the gate. (See miter gate limit switch locations shown in Plate B-67.) Since the gate's bottom seal resistance will prevent the lower portion of the gate from closing properly even though the top is mitered, only the top miter limit switch and the rack-mounted gate-mitered limit switches must be actuated before the corresponding filling or emptying sequence can be started. If, after the valves are opened and at least one of the lower gate mounted miter switches is not actuated, the valve being opened will automatically close. A logic diagram for this system is shown in Figure 2-12. A manual backup system should be provided for gate and valve control should the automatic control system fail. The manual control system is independent of the automatic control system and bypasses all gate-valve interlocks.

(f) The electrical controls systems utilize either electro-mechanical relays or solid state controllers. The electro-mechanical relay system for the valve/gate interlock system is shown in Plate B-66, Sheets 1-5. The same type of diagram can be used if solid state controllers are to be used. Miscellaneous power and control diagrams are shown in Plate B-65.

(g) In case of a control system failure that could shut down the lock, a backup system should be provided. One backup system used on several locks is indicated in Plate B-70. The manual backup panel is connected to a receptacle located under each console. When connected and a transfer switch is placed in the "backup" position, the operator has direct electrical control of the solenoid-operated directional control valve. When in use, the panel bypasses all automatic control and electrical interlock features.

(2) Electrically operated machines. At projects where floodwaters will not overtop the lock wall or machinery recesses, a modified Ohio machine with electric motor drive may be economical and desirable. At these projects, control equipment consists of the combination of full voltage magnetic controllers, limit switches, and control switches arranged to produce the desired operating sequence. The limit switches used in previous designs were of the traveling-nut type in NEMA four enclosures with heaters. Due to the unavailability of travel nut limits switches, cam-operated switches are being used. Control consoles similar to that described above for the hydraulic system are usually used. Electrical valve-gate interlock features should be similar to that described above for the hydraulic system. Strut stress limit switches are used to cut off the motor if the strut stresses in either tension or compression beyond a preset point. This will protect the strut and machinery if an obstruction is encountered. A typical electrical schematic of a control system using a single-speed motor is shown in Plate B-71. Control for a two-speed motor is shown in Plate B-72.

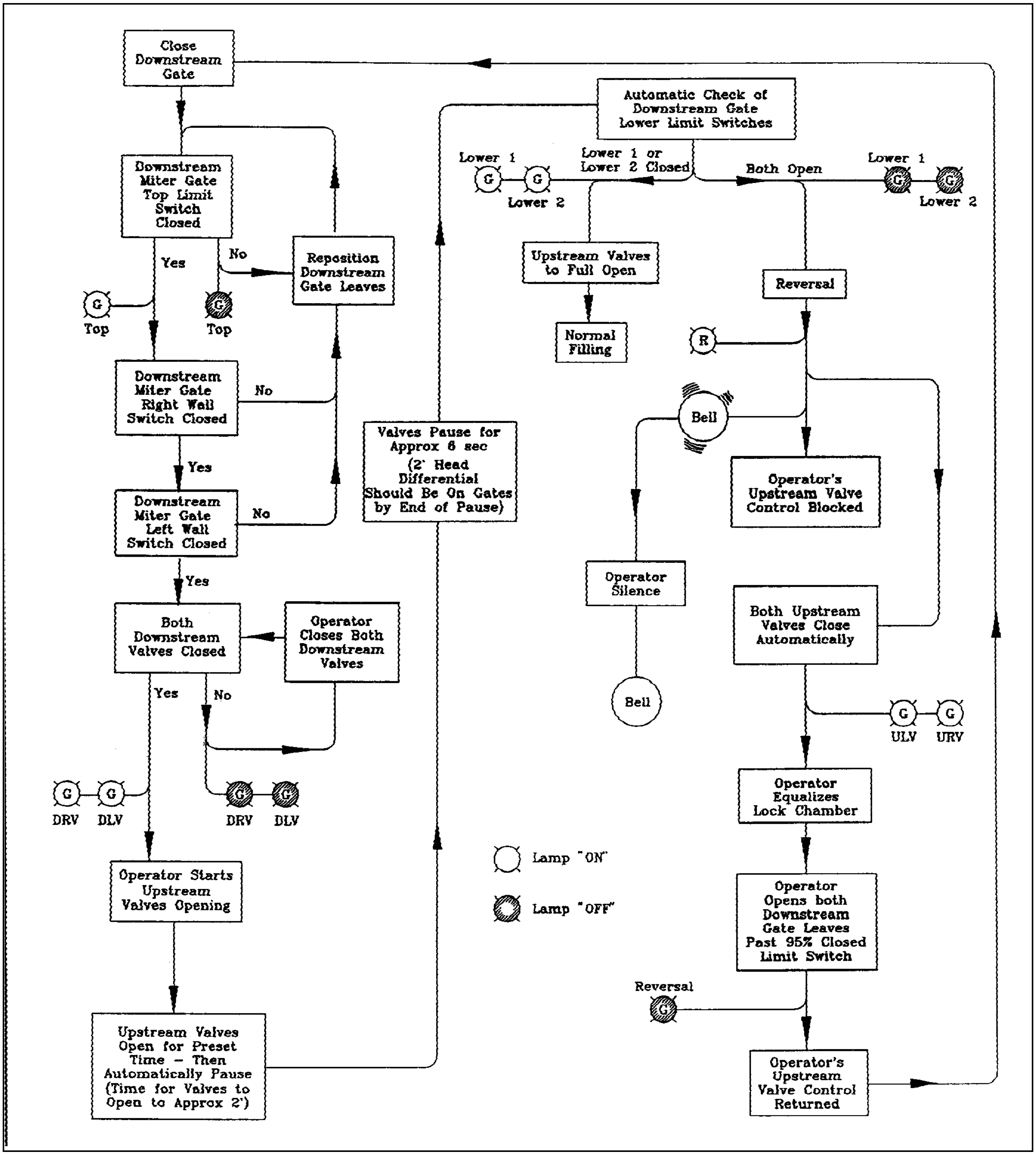


Figure 2-12. Lock filling sequence. (Lock emptying sequence is similar.)

f. Miscellaneous equipment and systems.

(1) Machinery stops. In order to deal with ordinary construction tolerances, a means must be provided to adjust the miter gate machinery linkage at installation. It has usually been found satisfactory to provide approximately 2 in. of overtravel at each end of the hydraulic cylinder and rack to allow for adjustment. With the linkage connected and the miter and recess positions established for the gate, stops are installed and adjusted to limit the machinery motion to these extreme positions. One stop is placed so as to stop the rack when the gate is mitered; another is placed to stop the sector arm when the gate is recessed. Details of this arrangement are shown in Plate B-49.

(2) Automatic greasing. A system should be provided to automatically grease each miter gate pintle bushing and gudgeon pin as shown in Figure 2-13. The system should dispense a measured amount of grease to each location automatically during gate movement. An automatic grease system is available with a built-in programmable controller, which will allow variations in grease cycles and quantity of grease provided. Since the grease systems have to be field-tuned, for a particular lock application, the programmable controller should be a desirable option. The pintle bushing should be designed to permit the installation of an O-ring seal and a grease return line which can be monitored to ensure grease delivery to the pintle bushing. The system should include automatic monitoring equipment to warn of a malfunction. Special consideration should be given to the layout and sizing of the grease lines to ensure proper operation and minimum pressure loss. Grease lines should be stainless steel pipe of adequate wall thickness for the anticipated pressures. Grease lines should be located in areas of the gate that afford the greatest degree of protection from damage due to ice and drift. The pumping unit should be located near the gate to minimize grease line length. Provisions should be made to remove the pumping unit if flooding is likely. For more details, see Plate B-13, Detail A.

(3) Automatic gate latches. Latches should be provided for holding the gates in the recess. The latches should be designed to automatically latch the gate when it comes into the recess. Release of the latches should be accomplished automatically each time a "gate close" function is initiated. A recess latch is shown in Plate B-68. The system should be provided with latched and unlatched position indication.

(4) Maintain pressure system.

(a) A maintain pressure system should be provided to hold miter gates closed with hydraulic pressure. The present system (as indicated in Plate B-66) is designed to hold the gate leaves together against wind loading or small water surges prior to changing the chamber water level. Upstream gate maintain pressure is used during lock pit emptying, and downstream gate maintain pressure is used during lock pit filling operation. This maintain pressure system is activated by the lock operator depressing a pushbutton on operator console. This system can be deactivated manually by the operator or is automatically deactivated when the gate under maintain pressure is opened or after the valves are opened for a predetermined time to allow an adequate head of water on the gates to keep them mitered. The maintain pressure system should utilize the valve "slow" or the lowest pumping rate available.

(b) The tandem center hydraulic system is not preferred but, if used, or if retrofitting a tandem center system, the maintain pressure system will provide pressure to the miter gate cylinder in the gate closed position through the use of a standard bladder-type accumulator. This accumulator, located in each miter gate machinery recess, will be charged and pressure maintained through a pilot-operated check valve installed in series with each miter gate cylinder. A pressure switch, sensing accumulator pressure, will ensure adequate pressure through a time delay circuit. An indicator lamp on the control console will be illuminated when pressure in the maintain pressure system is adequate. At the same time the gate four-way valve will be automatically shifted from "close" to "neutral" position.

(5) Fire protection system. In addition to the requirements of EM 1110-2-2608, a fire-protection system may be provided for miter gates. In operation, this system provides a dense spray of water on the miter gate surface between the gate and barges which may be on fire in the lock chamber. This spray would keep the gates cool and minimize distortion in the event of a fire. The system consists of a series of water spray nozzles located along the top of each miter gate leaf discharging into the lock chamber. These spray nozzles are fed by high capacity raw water pumps. One pump is provided for each lock chamber. Control stations are located near each gate with controls for starting and stopping the raw water pump and also for opening and closing the motorized valve in the supply line to each set of gate nozzles.

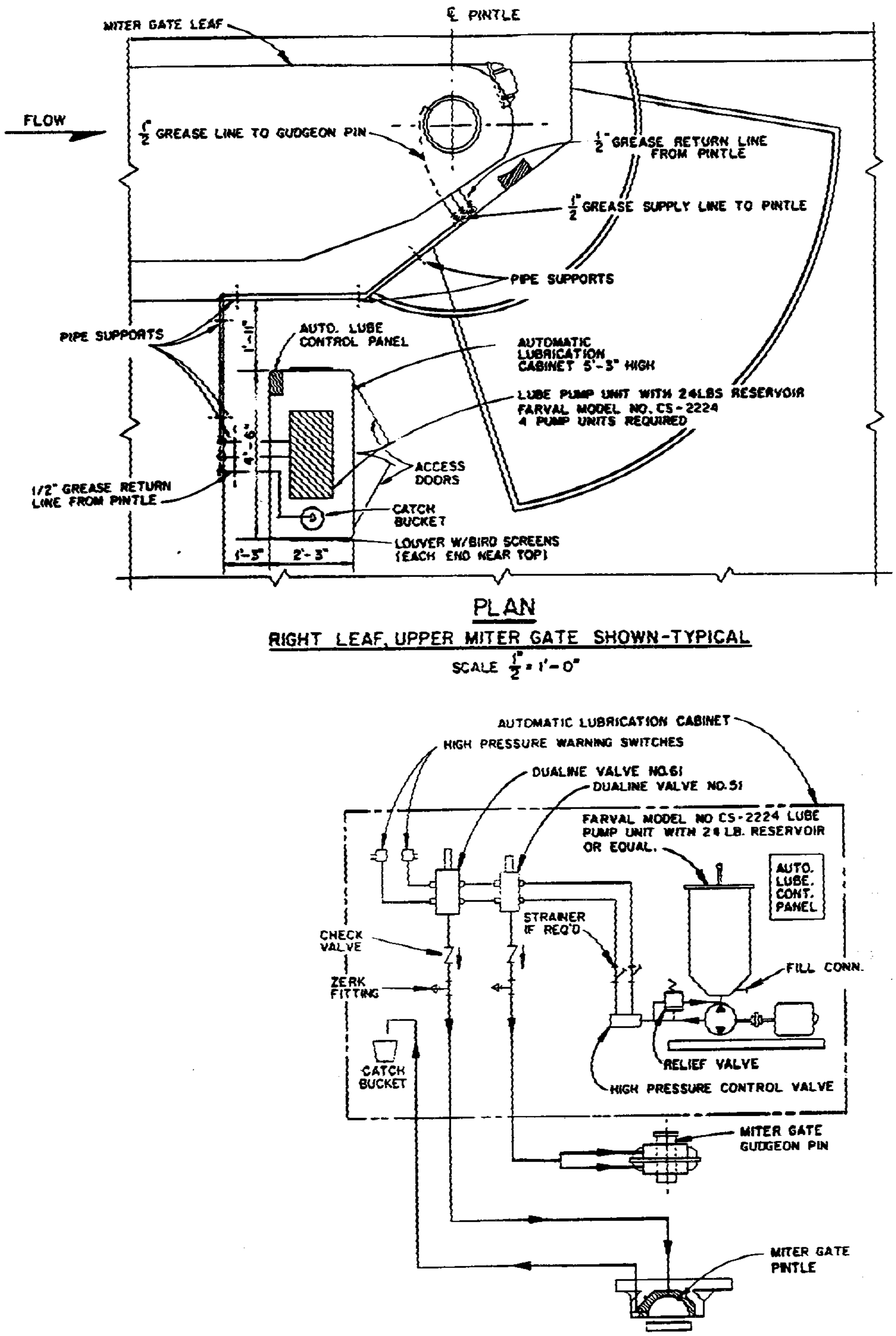


Figure 2-13. Automatic lubrication system schematic

The decision to include the gate spray system should be evaluated on a case-by-case basis depending upon the consequences of the loss of the gate.

(6) Overfill and overempty control system. The overfill and overempty system should be evaluated on a case-by-case basis and should be considered mainly on high lift locks or locks with long narrow approaches. A control system has been developed to eliminate overfilling and overemptying of the lock chamber. This system measures water levels by sensing the back pressure of compressed air constantly bubbling through tubes extending below the surface of the water. This system compares the level of water in the lock chamber with that of the upper pool when filling and the lower pool when emptying and at a predetermined time begins closing the fill or empty valves, respectively. This action dissipates the energy of flowing water in the culverts, thereby eliminating lock overfill or overempty. The operators at locks which utilize the gate-mounted limit switches have developed an operating technique which eliminates or greatly reduces overfill or overempty. As the lock fills or empties, the operator watches the indicating lights controlled by the gate-mounted limit switches. When the lights start going off the operator opens the appropriate gate.